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## NEW TECHNOLOGIES IN RESEARCH, EDUCATION AND PRACTICE

# Contents

# Competence Improvements with IoT systems

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**Abstract**. The informatics/programming education in high schools rarely put the new information in context. Thus, the students cannot see the Big Picture, it makes hard to see for them why the new curriculum is important, what kind of problem we would like to solve with it. The main purpose of this research is to identify this issue by asking first semester university students about system related question and to find a solution by using IoT systems in education in or-der to improve their competencies.

**Keywords**: programming, informatics competencies, real-time systems, embedded systems, raspberry pi, systemic thinking

## 1. Introduction

Most often, the *algorithmic thinking* competence comes to front during the high school programming education. In universities as well, it is also true that the focus is rarely on the real-life, complex problems, where multiple technologies, paradigms must be used in an integrated way. The reason why it is an issue, is that the student cannot step out from the concrete tasks from the curriculum, they are not able to see the big picture. For example, we teach the databases in high school [1], but they have no chance to see a live database with a real application, or at least see, why the databases are so important.

In one of our previous articles, we highlighted four from informatics competencies [2], when we tried to find an answer for "with what kind of exercises should we teach the programming" [3]:

- Algorithmic thinking
- Data modelling
- Modelling the real world
- Systemic thinking

At this article, we try to prove, that there are technologies, there is a way to create curriculums to the specific student group (according to their age, interests, goal of the teacher etc.), that includes the improvements of those four competencies (and others of course), so the learners can step out from the *layer of unique elements*, from the usages of the concrete tool to a *systemic layer*, therefor they are able to see the items of the new knowledge in context, they get a different approach.

Our examples are the *IoT*[1] *systems*. We try to explain what we would like to/can teach with these tools. At the second part of this article, we prove that the issue is really exist among the students by the results of a questionnaire.

## 2. Modules of programming education with IoT systems

In an earlier study [4] based on other articles and university syllabuses [5, 6, 7, 8] a figure was made, where you can find the key modules in a hierarchical order, what shows the elements of a possible

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[1] Internet of Things: Complex system of interrelated devices, which are usually small with one specific purpose. Those devices are constantly communicating with each other (machine-to-machine communication) through a network. The IoT systems are mostly build up with embedded, real-time computers.

IoT curriculum. The original diagram changed a bit since then, we extended and modified it. The updated representation is the first figure.
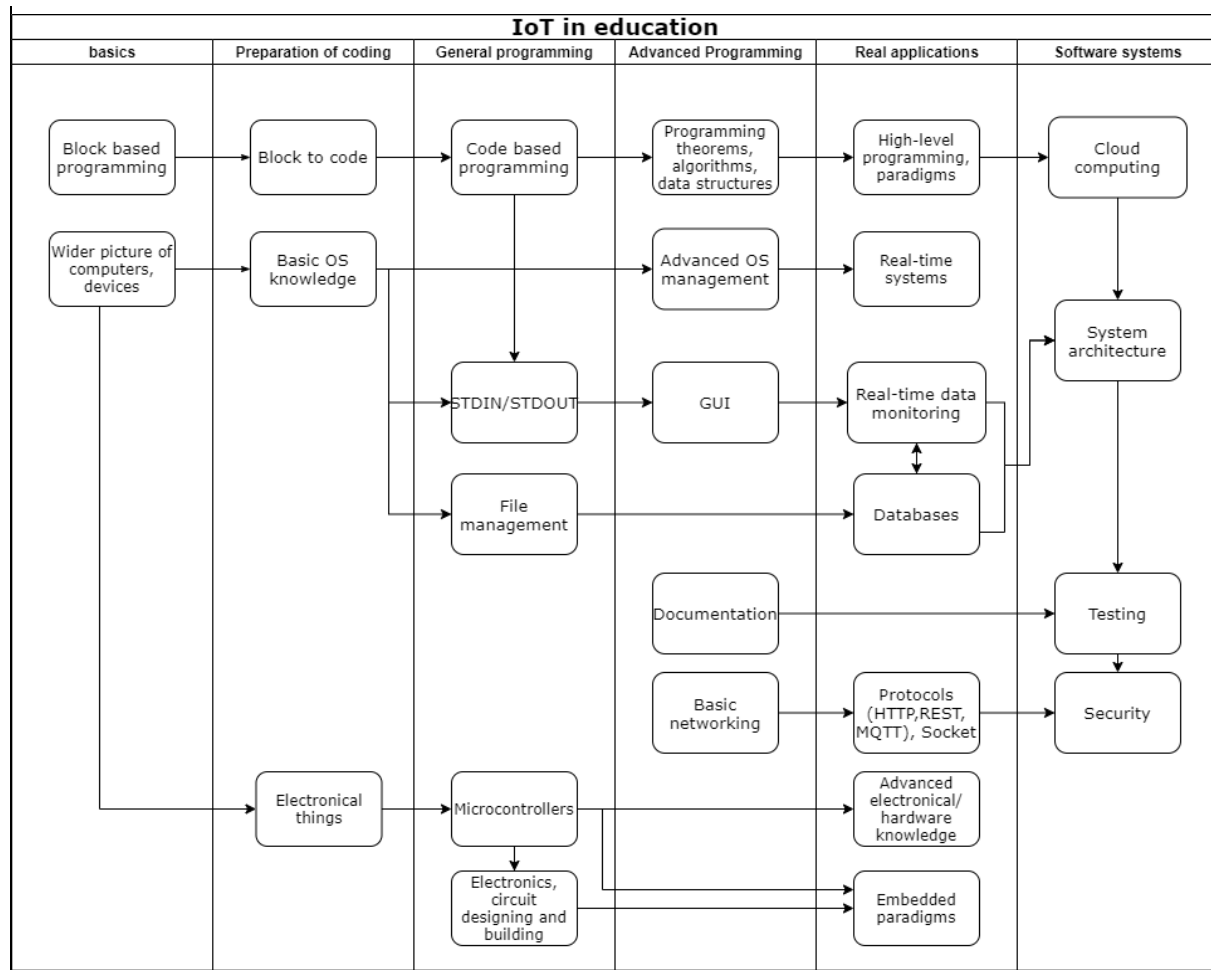


**Figure 1:** Modules and the hierarchy between them, that can be taught with IoT systems

However, the figure is applicable not only for IoT system. For example, the GUI, database, testing can easily be the focus in a completely different project from IoT systems. From that point of view the figure is the relationship of small elements and the big picture, and indicates many other questions, because the "the operational components, solving the part problems does not cause the operation of the system" [3]. The main purpose of this article is to prove the hypothesis, that even if the students have already learnt a module, they are not necessarily can interpret that from a higher level or can apply it indirectly, for example if we would ask "in what situations, when we should use a database for what purpose" and not "what the database is". If the proof is successful and the above figure is accepted as a suitable description of programming education with IoT systems, then we have an applicable type of curriculum what is scalable, where the focus point is movable, and what is capable to show the unique elements of a specific problem, and demonstrate its operation in system level at the same time. So, what are the embedded, real-time systems add to programming education? A toolbox to the teacher's hand, that allows them to build a curriculum, that is spectacular, scalable, what is based on the age, background, interests and of course the knowledge of the instructor's wishes and knowledges. Furthermore, with a project in this topic, the students can easily step out from the world of separate elements, so it gives a broader knowledge to them.

## 2.1. An example

We would like to illustrate the description above with a short syllabus (1ˢᵗ table), which was taught at ELTE with MSc students within *Embedded and Real Time Systems* subject. We moved the focus to *real time systems* just because that was the requirement against the subject. We think that it illustrates well that the IoT systems comes with a great opportunity, includes many technologies and programming paradigms and makes easy to educate the main informatics competencies where the students have no other option but to work and think in systems, they must find solutions that includes many co-operating modules.

The basic assumption was that we would like to build a smart home project based on *Raspberry Pi-s* [2] so that the system is capable of expanding with additional tools (example: a new smart room). We also wanted to monitor the whole system with a graphical application. Of course, important data should be accessible via the internet, and they had to build a local *IoT gateway* as well (which is critical in the industry).

| Lesson | Description |
|---|---|
| 1. | **IoT opening:** A quick review about the topic and a demonstration of a real *IoT* project (*real time* data visualization) **Assemble the devices** Go live with the hardware and example codes • How to communicate the *Sense Hat* [3] module (get sensor data, display something in the LED matrix)? • How to control the camera module [4]? • tkinter Python package for GUI applications |
| 2. | **MQTT protocol** Install and configure an MQTT broker and use it for local communication. Use the codes from the previous lesson to get data, and publish it to the broker, subscribe for events and display the incoming information. |
| 3. | **Cloud services** Configure a Firebase real-time database and write create a com-plex Smart Home simulation |
| 4-6. | **IoT lab** – Create independent applications, simulations of a real-time problem (they get the final grade for that project) |

Table 1: An *IoT* curriculum in short

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[2] https://www.raspberrypi.org

[3] https://www.raspberrypi.org/products/sense-hat/

[4] https://www.raspberrypi.org/products/camera-module-v2/

We collected the items of the 1ˢᵗ figure, that was involved during these 6*1.5 hours. It can be seen in the 2ⁿᵈ figure, that there were a lot of items (at least at high school level). It can be stated that in a short time the students needed and could create a complex system.
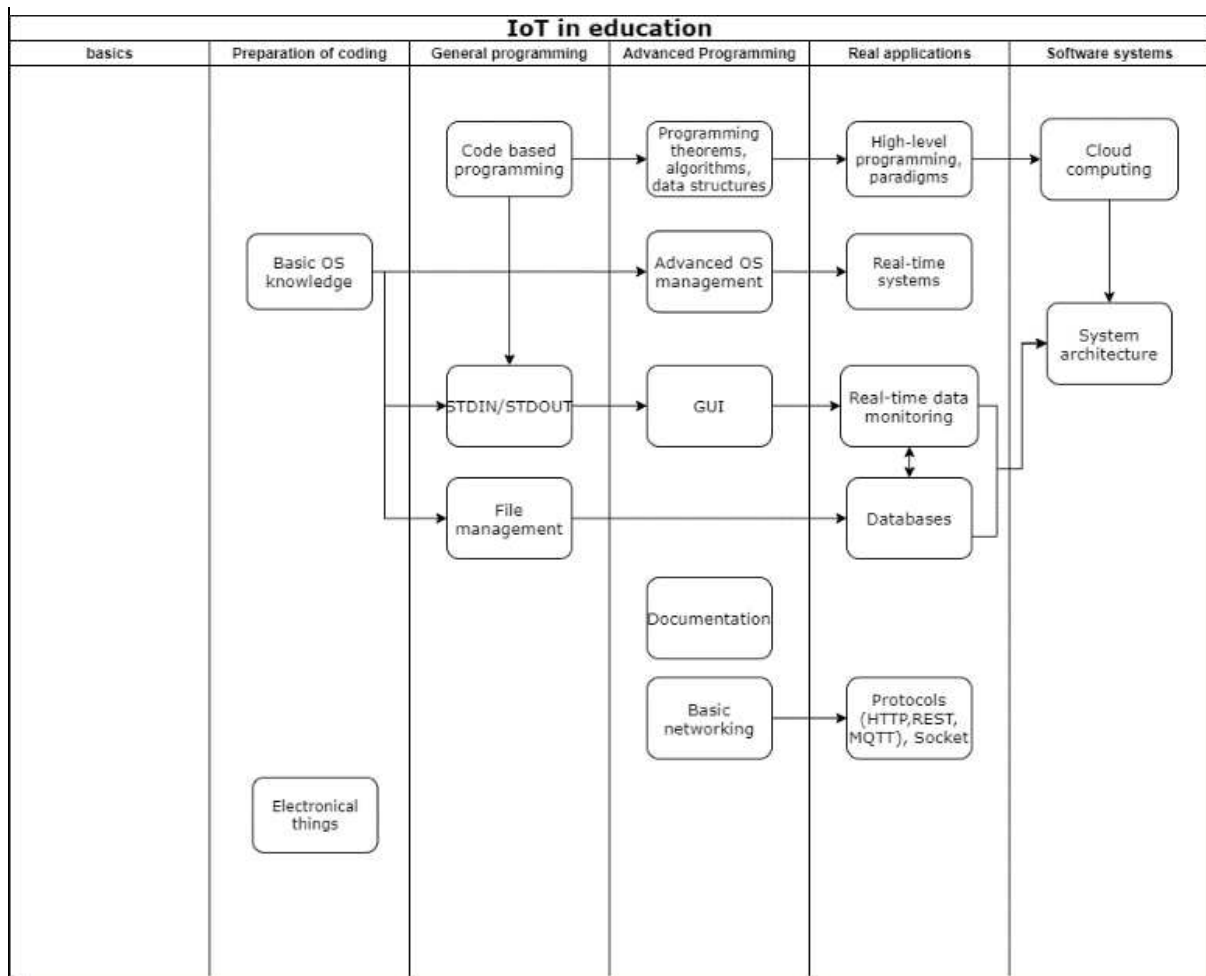


**Figure 2:** Involved items by the curriculum

The emphasis on scalability is very important. Of course, and exactly same curriculum cannot be presented in a high school, but this is not our goal.

The question is whether this project could be taught to high school students? As we see it, yes. For example, without communicating through the internet by using a *real time* database, or if we would remove the monitoring solution from the system. The building of the MQTT protocol is also not that important.

Is it possible to extend this project with additional items, so that we can show something more to the audience? Yes, there are opportunities, like autonomous testing mechanisms or making a safe *IoT* solution or replace the ready to use *Sense Hat* module with self-made complex circuits etc.

## 3. The questionnaire

The questionnaire was filled out by 205 first-year computer science students. The following aspects dominated the formulation of the questions:

- they must be at high school level or maximum what is currently studied
- even if the students give wrong answer to the question, it is still possible that he/she knows the curriculum, will complete the subject successfully
- the questions must about system-level competence, meaning that knowing the answers is essential when applying a particular tool / technology to a larger project, but not necessary when learning the tool

We will explain why these conditions are met for each questions one-by-one. For those that needed a short answer (free text), we had to categorize the result. It was really hard sometimes, because there were so many different answers. You will find those categories on the diagrams, and there will be some examples as well, to make them understandable. On the following section, you can find the questions and the results illustrated by diagrams.

### 3.1. Why do we store data in databases and not in files?

The database management is required in high-school graduation. The ability of the students to create tables, modify their contents, write queries in the concrete environment (like Access) does not make sure, that they understand the importance of databases, why they are really useful in real life. Data is stored in files in high-school and in the early years of university as well, so it is not necessarily clear how the databases came into the picture. However, later on it comes inevitable around real application to understand the persistence, transactions and other aspects of data storages.
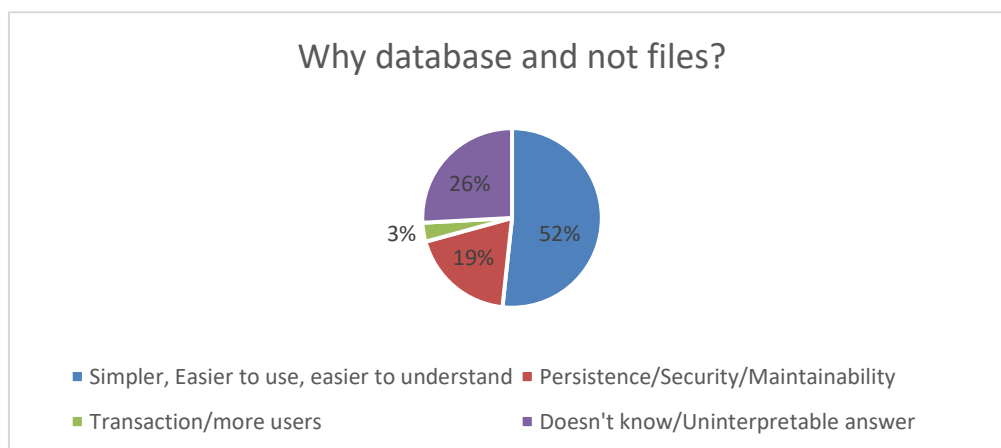


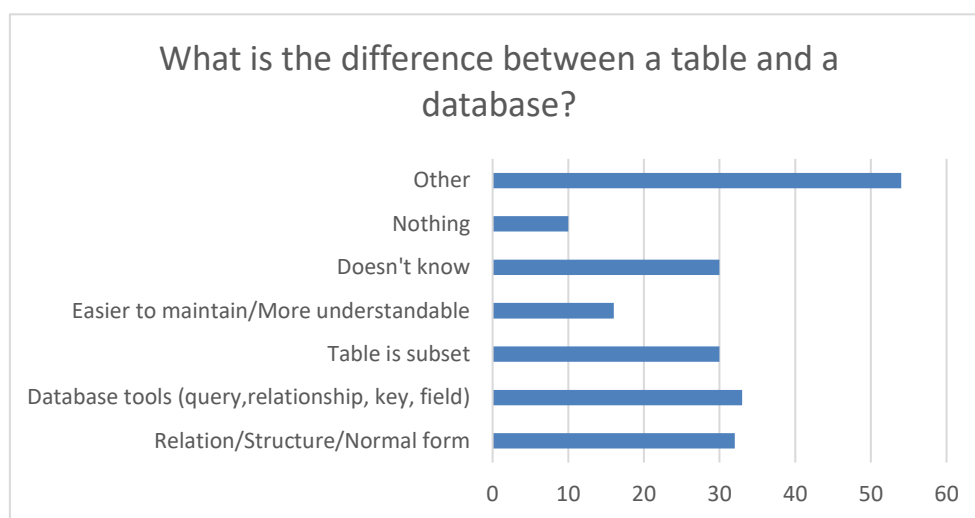**Figure 3:** Counted Categorized answers for the first question.

Actually, *persistence and transaction* were never mentioned. Those answers could get here, where we were able to see something that connects somehow to these concepts. The last category contains the answers that we could not interpret like "Compression".

Our opinion is that the result is really sad even if it proves our hypothesis: the students have absolutely no idea why we use databases.

### 3.2. What is the difference between a table and a database?

Here, like in the previous question, we wanted to ask about the wider usages of the database. In the intermediate education, students often do not understand why they need to deal with database

management, when spreadsheet tasks are very similar, and many of the database exercises can be solved with table management programs as well. To sum up, it is possible that the students can use the Excel and Access for example, without knowing what the real difference between them is. As a correct answer we would expect that the database is whole management system with several components for example tables, keys, indexes with its own layers like DML, DDL, DAL, a persistence- and data structure logic while a table is just a two dimensional structure with columns and rows. All in all, we do not expect a precise definition, just references what they have used before.



**Figure 4:** Counted Categorized answers for the second question.

The results for this one were really mixed and interesting. It was really hard to categorize the answers. We think that we were quite kind while figuring out the thoughts of the students. Of course, these answers were not specifically formulated. Just a few examples from the real answers:

- Relation/Structure/Normal form: We can make operation between the tables of a database as well.
- Other: The are more opportunities in a database; A database can be varied in many ways, while a table is more bounded at some level; A database is a table that had data in it; More things can be in a database.
- Table is subset: A database is a collection of tables; More tables

Thus, in the case of categorization, we were trying to categorize the student's reasoning, not the specific answer. Even with is kind method, a very interesting result came out.

The result is very surprising (4th figure), because they have certainly learned spreadsheet and database management in high school, but they do not understand the difference at all.

### 3.3. Identify where and in what form do you think you will use what you have learned about text editors?

Text/document editors are required in high-school graduation [1]. It is really important to be able to use and understand them, and not just for programmers. There are many general rules and tools that are almost the same in every capable environment (like an e-mail client, in a forum etc.). For example, they will definitely need to write documentations during their future work, where they

will have to use these knowledges, because they will not write it in the Word application. We have no idea whether they know something about the font-, paragraph-, section-level formatting, but it is not that important now. We just wanted to ask if they understand how they will use it. The correct answer would be something generic, not a specific program, tool or purpose, for example: in any software, where I work with a text.
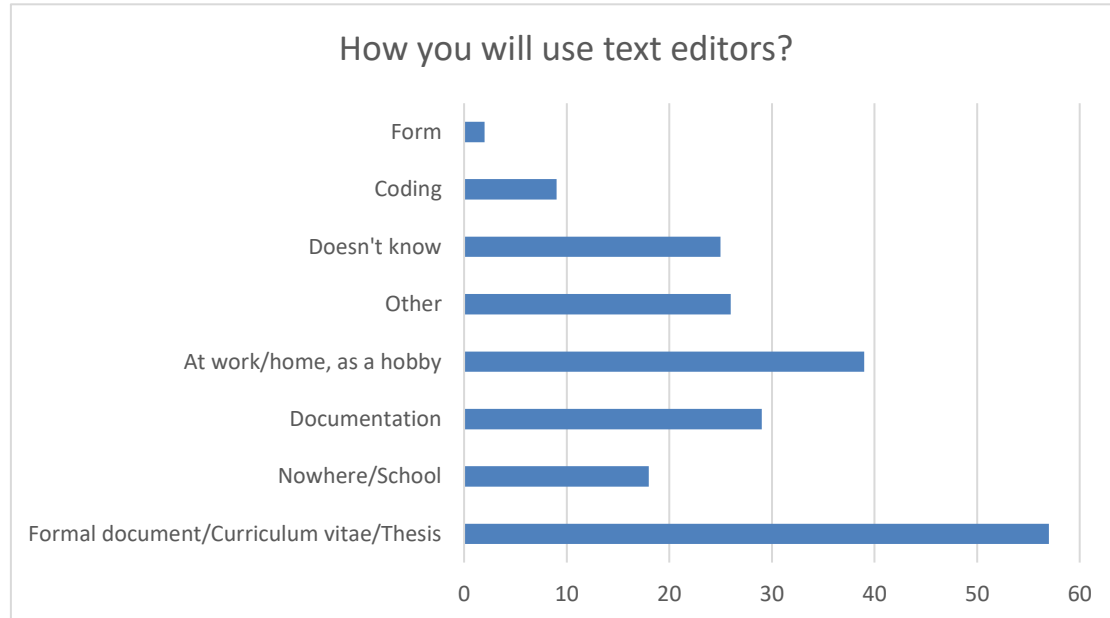


**Figure 5:** Counted Categorized answers for the third question.

When we constructed the categories, we highly focused if they answered the *In what form* question. Here we were thinking some general text editor item like there must be some font editing option, that follows almost the same logic as Word. As you can see in the $5^{th}$ figure, only 2 people mentioned that in any way. Just a few examples:

- <u>Other:</u> When I would like to edit some text.
- <u>Nowhere:</u> If I fail my studies, and I will be a secretary.
- <u>Design:</u> Formal editing

In our view, the data clearly indicate ($5^{th}$ figure) that the text editors could not be generally interpreted. There were so many concrete document types (last line), and there were too few that referred to some logic or pattern. What is particularly frustrating is how many people think that nothing is useful in that topic.

### 3.4. Let's say you need to create a new user in a remote Unix server. Define the general steps that you need to take!

The reason we asked this question is because the shell scripts are currently in the curriculum. In response, we expect is something like:

- SSH connection with the remote server with admin permission
- Executing the right command with the right parameters

They didn't learn how to create a user by using the command line. The point is to make sure that they understand how they will use what they currently learning (the shell environment) and

understand the general structure of what problems they will be able to solve through it. If someone cannot answer this question, that does not indicate that they are not able to pass on the examination, because they just need to use already learned and practiced commands.
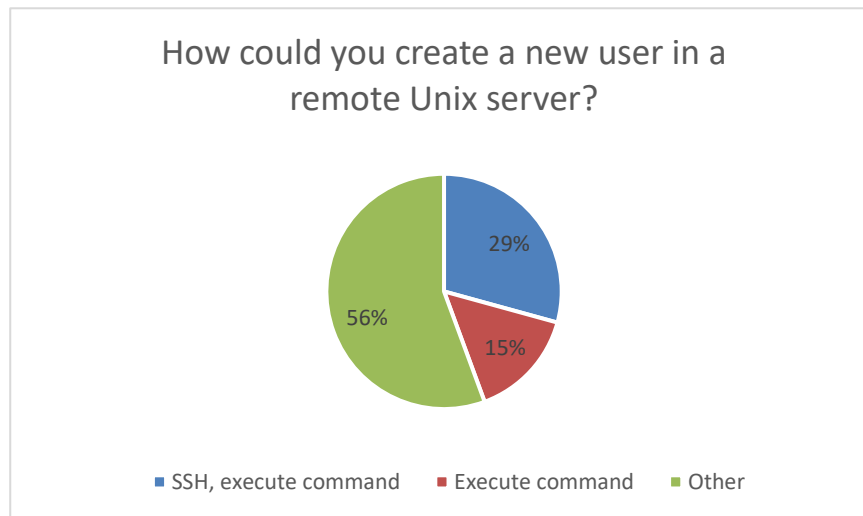


**6th figure:** Counted Categorized answers for the fourth question.

When we identified the results, it was especially true, that completely distant answers were also put into the above categories. For example:

- <u>SSH connection</u>: Connecting to the server, creating the user
- <u>Execute command</u>: Google

Tried to focus on the thoughts of the students. For example, if the answer is "Google", than he/she surely thought about finding the right command.

However, what is clear after understanding the results, is that they cannot identify a problem as a workflow, but they expect something more specific, that connects directly what they have learnt. Of course, we are not saying that they could not solve this problem in real life. We are saying that they had not learn the *system thinking* in the education system, they will do it on their own.


### 3.5.   Let's say you must create a web-shop. List the layers of the application!

We expected the database-backend-frontend as the right answer. They have met with database and frontend before (high school). They may have not met the backend layer yet, because there is no such subject in the first year of the university. Nonetheless, application layering can be expected from the student, regardless of whether he or she can write queries or not. The hypothesis of course that although it could be expected, but they cannot define the layers, despite they know them separately.
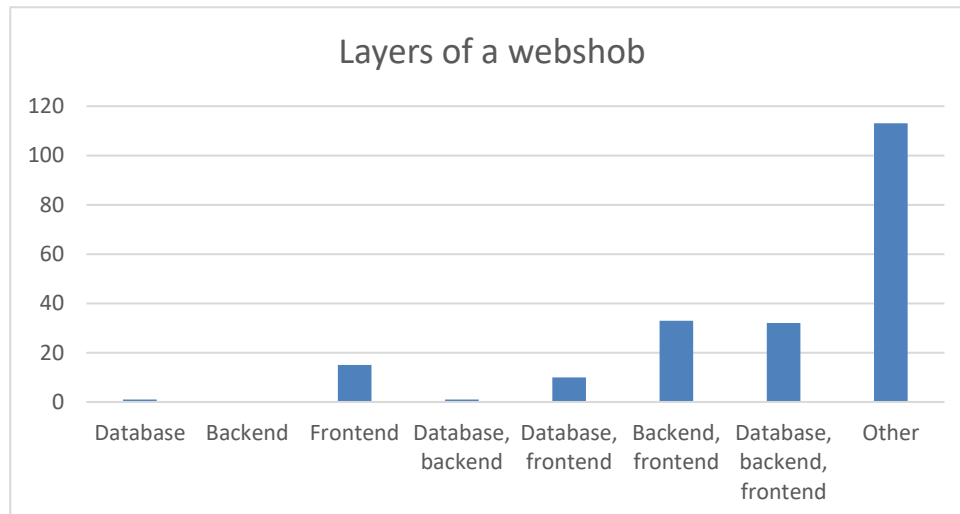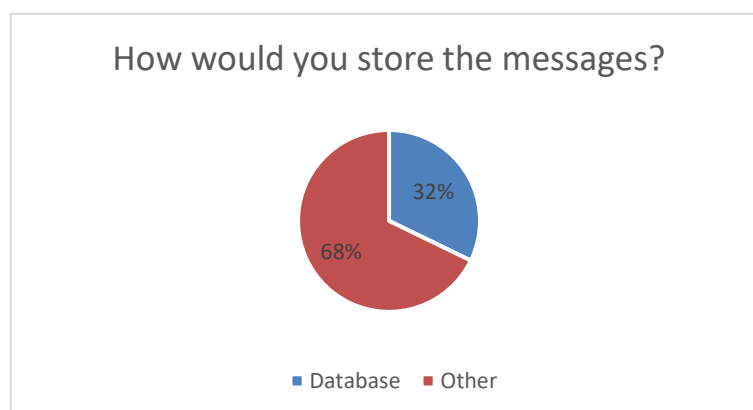
**Figure 7:** Counted Categorized answers for the fifth question.

The last set of data in the seventh figure includes the answers where there was nothing correlated to layering or it where the student divided the layers in completely different way (e.g.: web page functionality). Since the rest of the data is below the number of responses in the *Other* category, our suggestion was correct. Some examples:

- Database, backend, frontend: Design, servers, storage for goods; Appearance, background scripts, databases
- Database, frontend: Paying software, pictures, prices and products database, data storage database.

### 3.6. If you had to write a real-time chat application, how would you store and manage your messages?

The question was formulated specifically to give an example where the task is not to learn technology but to connect the technology to a real problem. As an answer we expected any reference to the database. Anyway, this question's strong part is that it cannot be answered without a programmer's thinking. It is already valuable, if the student realize that the answer is an information technology.



**Figure 8:** Counted Categorized answers for the sixth question.

To be honest, we expected that this question will not prove our hypothesis not least because the first question indicated that it is worth storing information in a database. However, eighth figure shows very nicely that when approaching the problem, they cannot recognize a learned technology yet.

### 3.7. True or False? In C++ language, cout writes the given string into the console.

During the first semester, students learn to program in C ++ (as well) so they must know the given function. Of course, the answer is no, because the text will go to the standard output, which is not the same as console. If they use the language to implement basic algorithms, data structures, some general small solutions, they won't see the importance of standard output, just the console to see their small results. Later, it will become more and more important mainly because of the background services and applications (and their output). The issue especially interests us, because shell script writing is also being studied now, where redirection is heavily on the curriculum.
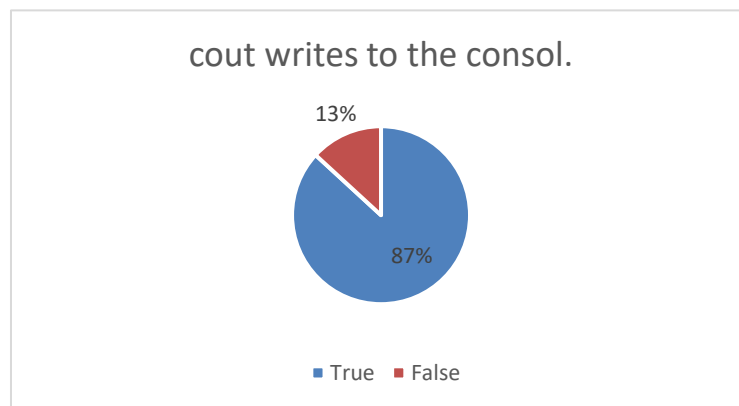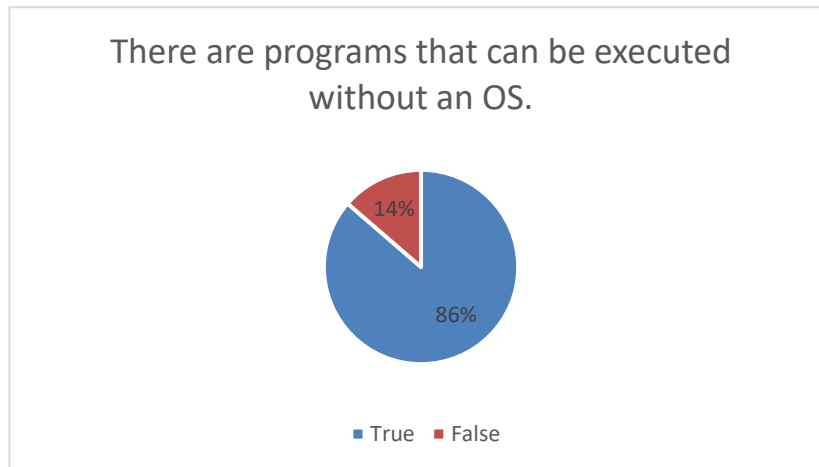


**Figure 9:** Summarization of the answers of the seventh question

At this question, they had the options, so we should not have to calculate, or categorize, we just counted the answers. The result (Figure 9) is striking students remember the command, they can use it, but they rely on their specific experiences, which are based on specific tasks, but they do no generally understand how it works. Since they have learnt that the standard output can be redirected, they have two coherent, but small knowledge elements, but they are not able to put them together to a system.

### 3.8. True or false? There are programs, that can be executed without an operating system.

We were wondering if they understand what happens when they run a program, whether they can distinguish the software from the environment. As they learn to write shell scripts, they have met situations, where the source code is executed by another program, but in other subjects, they learn C++, where the source code is compiled to machine code. The right answer is "true".
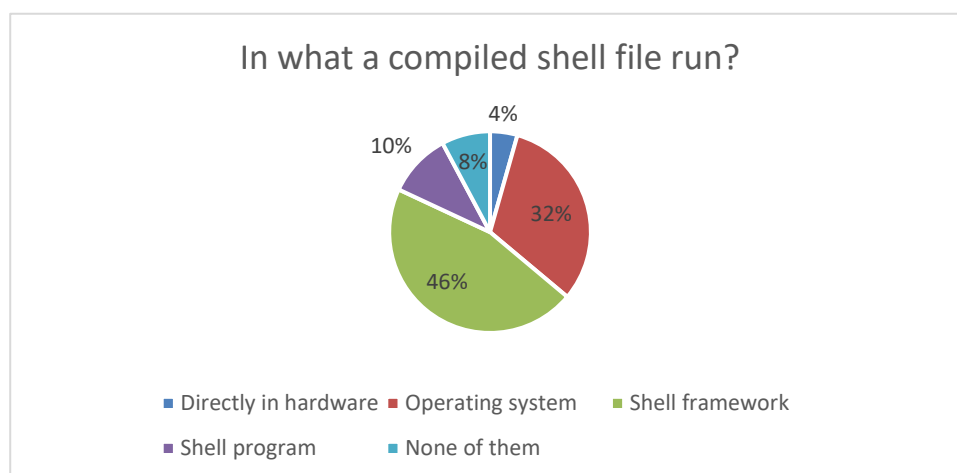
**Figure 10:** Summarization of the answers of the eighth question

This result (Figure 10) does not prove the hypothesis. The answers indicate that the students may understand what is happening while compiling the program. However, based on the next question's results, we are not sure that this is indeed the case.

### 3.9. In what a compiled shell file run? (directly in hardware, OS, Shell framework, Shell program, None of them)

With this question, we wanted to concentrate something current, what they do in their everyday university life. Perhaps, this is the most intrusive element in the quiz. The question itself is meaningless, as the shell script cannot be compiled (it is possible to translate the shell script into a C language and compile it after all, but we cannot expect, that the students met with that tool before) because the shell program will interpret it in real time (the definition of scripts). If the students do not know the answer, than we have a really strong proof for our hypothesis, because this is the thing, that they are currently studying (furthermore, most of them are completing the quiz during the lecture of the shell script subject). We can say that most of the students are able to write shell scripts on their own, so they likely to be complete the subject. On the other hand, it is possible that execution will remain as a black box for them.



**Figure 11:** Summarization of the answers of the ninth question (multiple choices)

The result (11th figure) is shocking. We know, that this one was really tricky but even if the students trust the question (you need to compile your shell script), they should have not pick the framework option (as you can see in the 11th figure). For example the "shell program" option can be logical, because it would have mean that they do not remember what the differences are between a program and a script, but they do remember that the shell program will execute their script. During the semester, the corresponding lecture was held by one of the authors (ILLÉS Zoltán), the other (KOROM Szilárd) was also there so we can say that they have never heard about a thing like "shell framework" (in the university). Of course, it is possible, that some of the students have heard about different shell frameworks, but it is close to impossible that it is true for half of the students. Furthermore, it is not true, that a shell script generally executed over a shell environment or framework. All in all, a small amount of answers could be relevant, but definitely not that much.

From the practices, we know that most of the students can write shell scripts on their own, so how is it possible that they have absolutely no idea what is happening when they try to execute it? From the results we conclude that because they are still in the *module* level (questions like writing concrete scripts, define the framework etc.). They can solve a single exercise, because they meet only these kinds of question but usually, we do not talk about the big picture, we do not see the problem from a system level.

### 3.10. Is it possible to run something that is not a machine code in the CPU?

This item is about the relationship between the hardware and the software layer. We often encounter the question among high school students, how the used application (e.g.: Word) connects to the hardware layer that works with circuits and bits? It is easy to avoid the bottom layer even for a developer, for example if he/she will work with a high-level programming language like java, C#. To sum up, it looks important, but this one does not refer to *systemic thinking*, just a unit question, so we just talk about a basic, pure CPU without any extensions (the question is not about various technologies, but about basic conceptions, if they understand the fundaments).
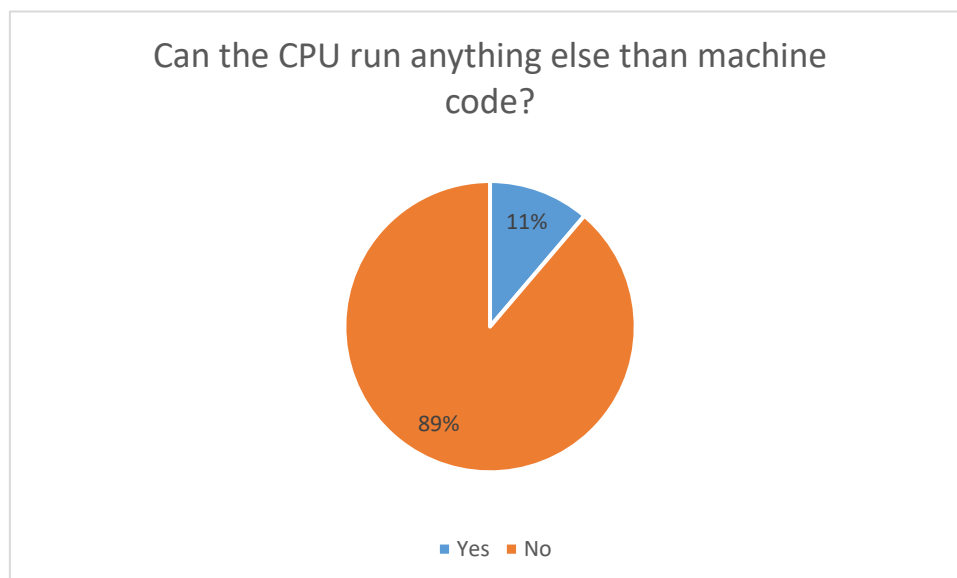


**Figure 12** Summarization of the answers of the tenth question

Figure 12 shows that the correct response rate is close to 90%, i.e. if the student receives a question he / she has studied and has to focus on a single unit (not at the system level, but at the level of individual components), than they can make the correct answer.

## 4.    Conclusion

We think that we could prove the original hypothesis, that even if the students know a *module*, they not necessarily can applicate it in a *systemic level*. The correct answer rate was close to 90% for the last question, which asked for a *module level* knowledge (12th figure). We have only one exception from the other items, where the students could not make the correct answer. In our opinion, the answers indicate many further questions (why they think that there is a thing like "shell framework"). We also had some shocking results.

We had to make categorizes for short answer needed question, but we would like to note, that it is possible, that other categorizes with different rules from different aspects could also be meaningful. For example, we also asked their programming experiences but in the context of the article we felt it was not possible to examine the answers in the light of this.

At the beginning of this study we tried to give border, technologies, methodology, that is applicable to step out from the *modules* into the *systemic thinking*. An IoT system drives the students to problems, where they must use several *modules* at the same time in order to build a complex working system. For example, they should have use database for building up real-time communications, connecting to the small devices without GUI, they made documentations and they also presented their solutions, they had to design a software system, so they could use different architectures. All in all, they were forced to build up an end-to-end solution with all its difficulties.

In general, a possible curriculum can be made for the different topics, what are scalable, the focus points are movable based on the students ages and knowledges. Proving that this is indeed effective has not yet happened, but it may in the future.

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## About this document

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# How Students Perceive Online Teaching IT Subjects within the MS Teams Environment

Martin MIŠÚT, Mária MIŠÚTOVÁ

**Abstract**. The presented research had two primary goals. The first goal was to determine students' attitude to lectures and exercises conducted through the MS Teams application. Students' attitudes to online teaching were identified by the students' activity within the subject Business Processes Modeling and students' opinions on the acquired knowledge's usability and applicability. Another goal of the research was to determine whether gender influences the perception of online teaching by students.
The obtained results indicate that the MS Teams application lectures are more acceptable for students than face-to-face lectures. Also, in such a lecture, students are more active, more often asking the teacher questions. Surprisingly, MS Teams exercises are not considered more useful by students than face-to-face exercises. The results further showed that women assigned lower values to most factors than men. The results of the research predict the influence of gender on students' attitudes to online teaching. Additional, It would be necessary to determine whether the difference between men and women's average values is statistically significant. This difference can be verified in a larger group of respondents. Therefore, we plan to continue the research.

**Keywords**: MS Teams, online education, attitude, computer subjects, digital technologies

## 1.    Introduction

Lectures and exercises are an essential part of an effective learning process. [1] Recently, it can be noted that the role of MS Teams-type technologies in teaching has grown to the point where we can talk about online education. Online learning can be defined as a process in which digital technologies are used to support and manage the teaching process. [2] In other words, online education deals with methods, processes, and web-based software tools (or systems) that enable students to acquire knowledge and skills with teacher support systematically. [3-5]

The growing number of reports on online forms of training courses is not surprising, given the potential benefits of this approach. These include (compared to traditional methods of education) cost and time savings due to access at any location[6]; a space for providing feedback that may have pedagogical benefits [7]; increasing the level of student activity due to the relative novelty and attractiveness of this approach[8]; increased flexibility [9], such as allowing students to submit assignments at a distance without having to come to a school. Some studies have tried to measure attitudes and perceptions of online learning methods, e.g. the authors in [10] proposed a model that predicts students' attitude to online education. However, there is a clear need for further studies to examine students' attitudes, perceptions and preferences regarding online learning methods, as the evidence to date remains largely inconclusive.

Numerous research studies have shown that the use of digital technologies helps to improve the educational process in informatics. [11] To support and improve the development of students' IT skills at universities, we have proposed a new teaching model. [12] The model emphasizes continuing education, activity, independence and creativity [13] and contains blocks of training as well as assessment and a database of tasks that require the application of knowledge. The acquisition of knowledge, which is part of the new teaching model, has been substantially reworked and adapted to technology. Because students were not used to this form of conducting lectures and seminars, we researched students' acceptance of online education.

## 2.    Research goals and methodology

The research had two main objectives. The first goal was to find out students' attitude to lectures and exercises realized through the application of MS Teams. Students' attitudes to online education were identified by the students' activity in the subject and students' views on the applicability in the study of other subjects and the usability of the acquired knowledge and skills in practice. Another goal of the research was to find out whether gender affects students' perception of online education. Based on the above objectives, we have defined the following research questions:

- What is the semantic profile of lectures and exercises implemented through the MS Teams application in terms of selected factors?
- What is the semantic profile of lectures and exercises conducted through the MS Teams application in the group of men and the group of women?

We used a questionnaire based on Likert scales to answer the research questions. Attitudes towards the subjects were measured using several 5-point scales in terms of selected factors. A value one corresponded to a negative attitude, and a value five corresponded to a positive attitude on a 5-point scale. Based on the completed questionnaire, we created a semantic profile of lectures from the subject Business Process Modeling regarding preference, activity, applicability in study and practice and readability of documents. We also created a semantic profile of exercises from the subject in terms of factors of preference, applicability in the study, the volume of acquired knowledge and usefulness.

Preference was expressed by students' preferences toward lectures/exercises through MS Teams or face-to-face lectures/exercises. Activity is expressed by comparing the number of questions addressed to the teacher in an online lecture compared to a face-to-face lecture. Applicability expresses the students' opinion on using knowledge and skills acquired in the online lecture in further study and practice, for example, when working from home. The readability of texts is expressed by whether the student is satisfied with more materials that the teacher shares through the MS Teams application compared to the materials projected in the face-to-face lecture. The volume of knowledge expresses the student's opinion on whether he will learn more in online exercises than in face-to-face exercises, as he knows how the teacher guides his classmates in solving their projects. Usefulness is expressed by the fact whether students consider the exercises through the MS Teams application to be more useful than face-to-face exercises.

The group of respondents consisted of 38 first-year students of the engineering study program Economic Informatics at the Faculty of Economic Informatics of the University of Economics in Bratislava (FHI EU). At the end of the semester, we asked students to fill out an anonymous e-questionnaire. The return rate of the questionnaire was 53%. The questionnaire was completed and submitted by 20 students. Of these, 30% were women, and 70% were men. The group included 85% of students who completed the bachelor's study program in Economic Informatics at FHI EU. The remaining students completed another program at the Faculty of Economic Informatics or a program at another faculty of the University of Economics in Bratislava.

## 3.    Research results and discussion

### 3.1.    Results for the whole group of respondents

The overall results (Fig. 1) showed that students watching lectures through the MS Teams application perceive them as more comfortable than personal lectures (M = 4.15). Lectures through

the application would be recommended to use in university studies (M = 4.40). They agree that the skills acquired in online lectures can be used later in the job, e.g. at work from home (M = 4.20). The materials' readability is better for them when the teacher shares the materials through the application compared to the materials projected in the presence lecture (M = 4.20). The average values of all four factors used to determine students' attitudes to teaching through MS Teams are higher than the fourth level on the Likert scale, which represents a positive attitude (a value of the third level represents a neutral attitude and a value of the fifth level a highly positive attitude). A slightly positive attitude was expressed only in a questionnaire item with the information that in the lecture through MS Teams, students ask questions more often than in the face-to-face lecture. (M = 3.3)
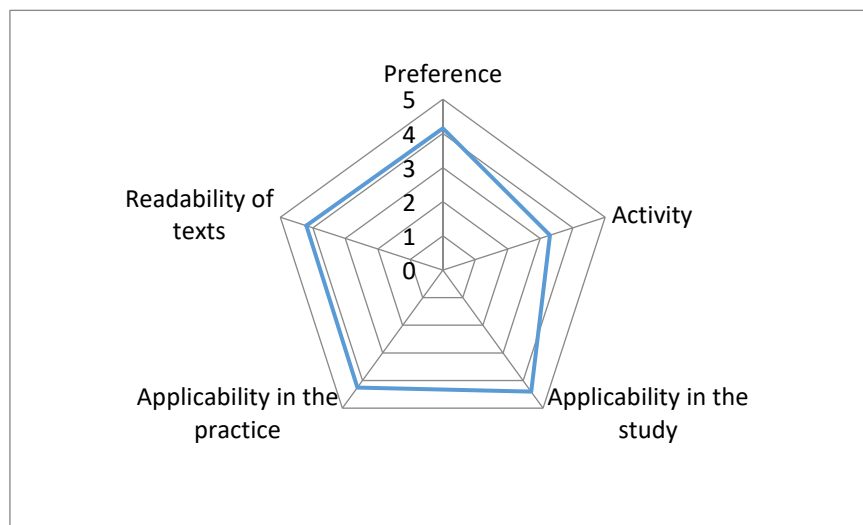


**Figure 1**: Semantic profile of lectures through MS Teams

The situation is different in students' attitudes to the exercises conducted through MS Teams application (Fig.2). Such exercises do not suit students more than face-to-face exercises (M = 2.95). Students assigned a low value to the recommendation to use this form of exercise in another study (M = 3.1). They also very weakly agreed with the statement that they would learn more in the exercises through the MS Teams application than in the face-to-face exercises (M = 3.1). Little did the fact that students know how a teacher guides classmates in solving their projects seeing directly in their screens teachers correction of classmates mistakes. Students did not consider exercises through MS Teams more useful than face-to-face exercises (M = 2.85).
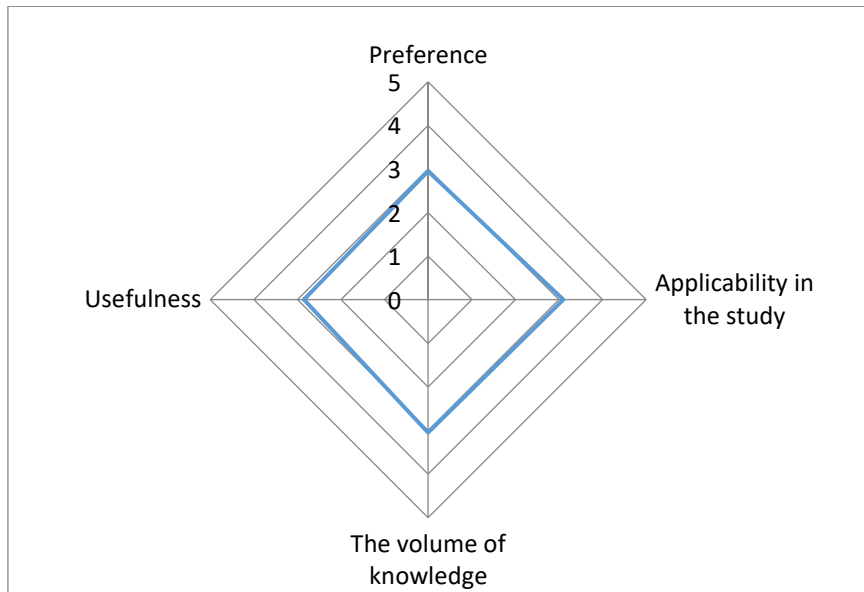
**Figure 2**: Semantic profile of training through MS Teams

## 3.2.  Results for the group of women and men

As can be seen from Fig. 3, the semantic profile of online lectures in a group of men is similar to the semantic profile in the whole group of respondents. In the group of women, it differs in the factor of readability of texts. Women perceive this factor with a lower average value (M = 3.5) than men and the whole group of respondents.



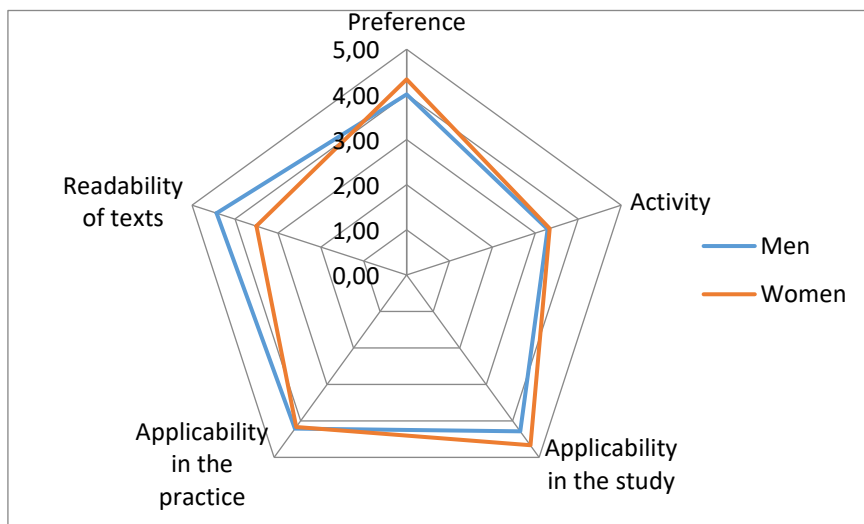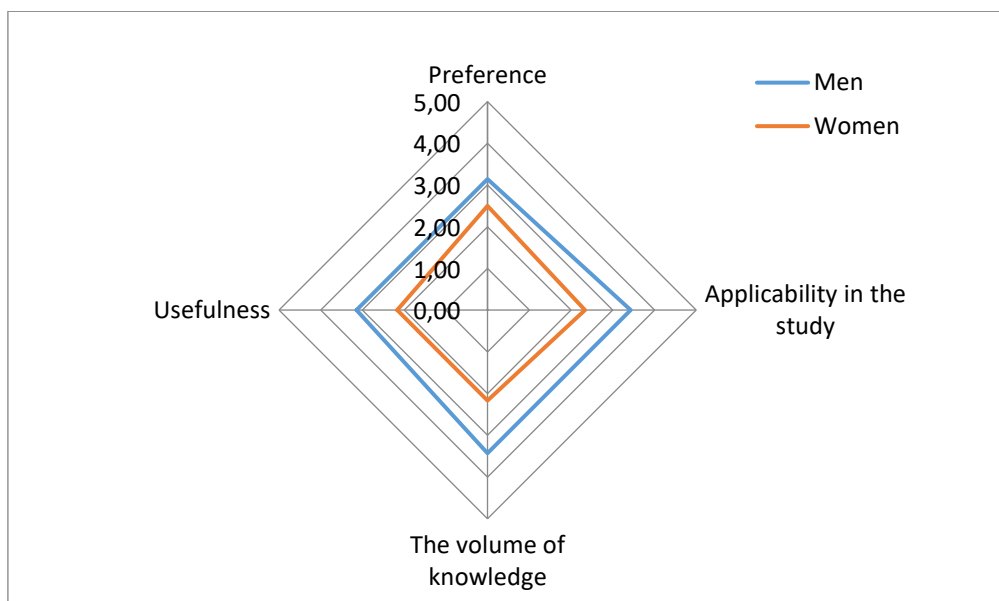**Figure 3**: Semantic profile of online lectures in a group of men and women

The obtained results suggest that although men and women assigned different average values to the readability of the materials from the subject, both groups were marked as better readable materials shared by teachers in the online lecture than the materials projected in the face-to-face lecture. The result confirmed our assumption.

**Figure 4**: Semantic profile of online training in a group of men and women

In the semantic profile of the online exercise (Fig.4), we got a similar result. Again, the semantic profile in the group of men is visually similar to the semantic profile in the whole group of respondents, although men assigned higher values to all factors. The factor of online exercise preference is different, where men assigned an average value of M = 3.14, which corresponds to a weak agreement; in contrast, in the whole group, the average value was only 2.95.

However, the group of women's semantic profile differs from the semantic profile for exercise in the whole group. Women assigned lower values to all factors than men. All average values are in the area of disagreement. The results of our research predict that gender influences students' attitudes to online exercises. To determine whether the differences in average values are statistically significant, we plan to repeat the research for a larger group of respondents.

The obtained results showed that students' attitude to online lectures is positive (M = 4.15). 80% of students expressed their opinion, as can be seen from Fig. 5, which contains students' answers to one of the questionnaire items. Only 15% (3 out of 20) of students expressed a negative attitude, and only one student has a neutral attitude to online lectures.

Also, the results suggest that attitudes toward online education are influenced by gender. This fact surprised us, as we expected the acceptance of online education in the group of men and women to be the same. This result needs to be verified statistically on the data of a larger group of respondents.
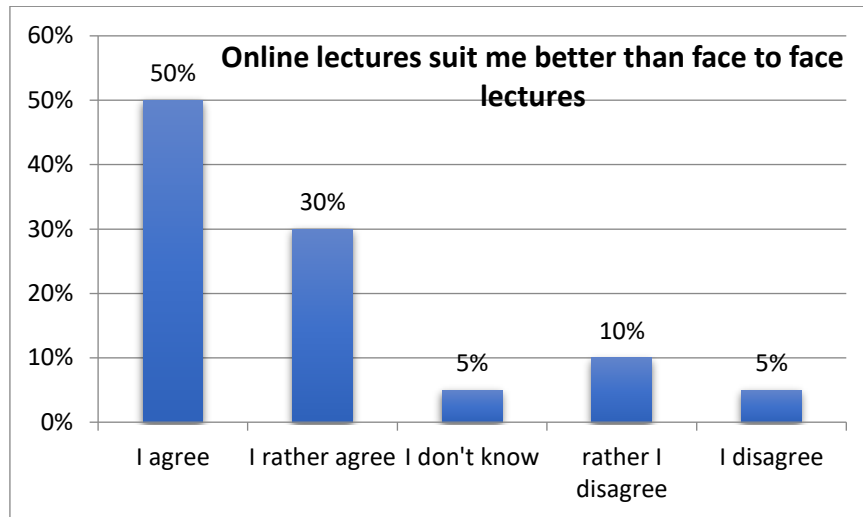
**Figure 5**: Students' answer to the questionnaire item

We were also surprised by the Business Process Modeling course students' attitude to online exercises. As can be seen from Fig. 6, only 40% of students prefer online exercises compared to face-to-face exercises. Furthermore, 45% of students would prefer face-to-face exercises in teaching. The conclusion cannot yet be generalized due to the low number of respondents. To verify this, we plan further extensive research.



**Figure 6**: Students' answer to the questionnaire item

## 4.    Conclusions

The presented research revealed two significant findings:

- Although there is a difference in the average values in the perception of individual factors depending on gender, students' whole sample perceives online lectures positively. They prefer

them more than face-to-face lectures, recommend using them in university studies, and recognize that they can use the skills acquired in online lectures later in the job.
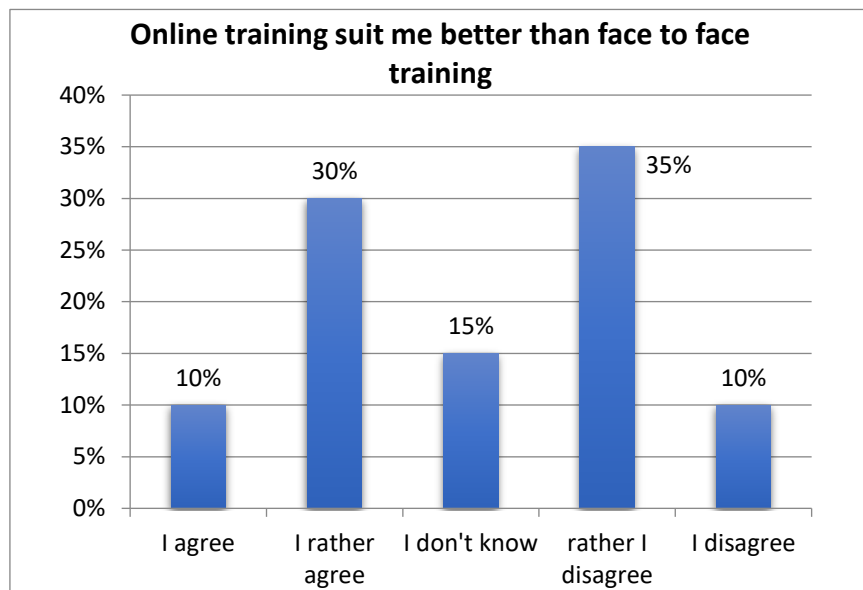
- Attitudes towards online exercises are no so highly positive. Online exercises do not suit them more than face-to-face exercises, nor do they find them more useful. However, they strongly agreed with the statement that they would learn more in exercises through MS Teams application than in face-to-face exercises and recommended to use them in further study.

The research confirmed that the form of teaching through digital technologies does not cause any problems for students. However, technology-based teaching significantly reduces costs and streamlines the learning process due to making it available anywhere. [6] We also noted an increase in students' active participation in online lectures compared to face-to-face lectures. The acquired knowledge is fully valid for the environment in which it was acquired. To verify validity in a broader context, it would be necessary to carry out similar research in other universities' environment and with a more extensive set of respondents. However, it can be assumed that students of technical study programs will have a similar acceptance of online education. We obtained the gained results presented in this article to adapt the teaching model, making extensive use of digital technologies.

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## About this document

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# Investigation of the Rotational Motion of the Fidget Spinner by Means of Technical Informatics

SOMOGYI Anikó, KELEMEN András, MELLÁR János, MINGESZ Róbert

**Abstract**. The boundaries between science, engineering and computer sciences seem to have been blurred in the 21st century. Microcontroller programming plays a role in informatics education, while modern physics teaching integrates the potential of computer simulations and computer-controlled measurement experiments. In order to demonstrate the latter, we present an experiment to precisely identify the dynamic causes of a kinematic phenomenon solved by means of technical computer science. To investigate the role of air resistance, we developed a vacuum chamber in which the signals of sensors were processed by the NI myDAQ multifunctional device and the popular Arduino UNO. A wide range of ways is presented to control data acquisition and numerical analysis of a pulsed signal produced by a photogate, as well as graphical representation and evaluation of derived time-dependent signals. Controlling the two devices due to their characteristics and hosting of measured data by a computer require different development tools from the user (LabVIEW, C/C++). The results and methods of the study can be applied in physics and computer science education at secondary school level.

**Keywords**: interdisciplinary education, technical computer sciences, Arduino, LabVIEW, Excel Data Streamer

## 1.    Introduction

In the 21st century computer sciences, engineering and science in general seem to have blurred boundaries.

Microcontroller programming plays a role in IT education. A good example of this is the spread of micro:bit in the UK [1], [2], which is programmable in Python and JavaScript or the inexpensive C/C++ based Arduino. The number of publications that use these boards has increased dramatically in the last ten years [3], [4]. At the same time, modern physics teaching integrates the potential of computer simulations and computer-controlled measurement experiments. The NI myDAQ multifunctional device - programmable in LabVIEW and developed for school measurement - is also gaining popularity. Members of the Hungarian Academy of Sciences' Research Group of Technical Informatics Methodology (among them, some authors of this article) are also working on the renewal of computer and natural sciences education, which is the basis of technical education in Hungarian secondary schools [5], [6]. Generally speaking, researchers see opportunities in software-controlled measurements to increase the popularity of fields of sciences mentioned above, as well as filling skill shortages connected to technical sciences by youth education [7].

## 2.    Impact of Information Technology in teaching the Scientific Method

The Scientific Method basically always starts with gaining human experience and collecting information (cognition, experiment, measurement). This is followed by the evaluation of data, the search for connections and their systemisation. Based on these, one can formulate general regularities and make a mathematical model (e.g. set up ratio pairs, equations, formulas). The model makes it possible to derive new statements, but these must always be compared to experiments [8]. Throughout human history, the development of measuring instruments has always led to the development of natural sciences [9]. Naturally, the advancement of computing technologies opens

up new doors to this day, as it can make measurement, evaluation, systematization and modelling more accurate, faster and more efficient in the detailed process [10]. We consider it important to introduce this modern role of informatics to our students starting in early childhood and to provide them with the means of inquiry-based learning. Combination of information technology and science can play a role in motivation: experiments embedded in information technology, as well as the enrichment of otherwise less popular natural sciences with IT content, have a motivating and attention-attracting effect. Instead of general principles, methods and procedures, we would like to present a computer-assisted examination of a specific physical phenomenon to illustrate how technical computer sciences can provide possibilities for interdisciplinary education of physics and computer sciences [11].

### Problem

In international literature on physics education fidget spinners are increasingly featured. By spinning the well-known game, the angular velocity of its high-speed rotation decreases over time due to braking effects [12], [13]. On several online forums, video sharing portals it is suggested (or declared) that the effects of air resistance or rather friction dominate [14]. When this easy-to-understand physical phenomenon is examined by the modern digital metering, the question in discussion is realized not to be an easy one. However, our computer-driven experiment will help uncover the cause-effect relationships behind the phenomenon.

### Objective

During the presentation of our examination, we try to highlight the applied IT methods and ideas which we hope will turn out to be applicable at various levels of education.

## 3. 'Hardware' used in the measurement

When looking at the kinematic characteristics of the rotational motion (e.g. angular rotation, angular velocity), namely answering the question "How does it move?", it is sufficient to connect a simple photogate to a sound card [15]. However, if aiming to answer the question "Why does it move that way?", i.e. the exploration of dynamic causes, then the two types of braking effects on the spin must be distinguished during the measurement. The idea came naturally, that air resistance could technically be eliminated by a control experiment performed in a vacuum.

### 3.1.   Measurement setup

An experimental setup was needed in which the movement of the fidget spinner could be examined at normal atmospheric pressure and also makes it possible to suck out the air around the toy and to repeat our experiment under changed conditions.

The fidget spinner was placed in a self-made vacuum chamber.  As a lid, a salad bowl was used, while the bases was a wooden board.  A ring – fitting to the mouth of the bowl – was cut from a silicone baking sheet and was stuck by neutral silicone sealant to the base. Obviously, it is not possible to manually spin the fidget spinner in a vacuum, so a DC motor (1 - 3 V, max. 6600 $\pm$ 10% RPM) remote-controlled by infrared transmitter and receiver was used for this purpose.

The motion detection photocell was constructed by placing an illuminating laser diode under the fidget spinner, and a phototransistor detecting the light beam and its interruptions above the glass. The air was sucked out of the chamber by a high-performance vacuum pump, and the inner air

pressure was monitored by a pressure meter. A schematic diagram of this self-designed vacuum chamber and a photo of the experimental setup are shown in Figure 1 a-b, respectively.
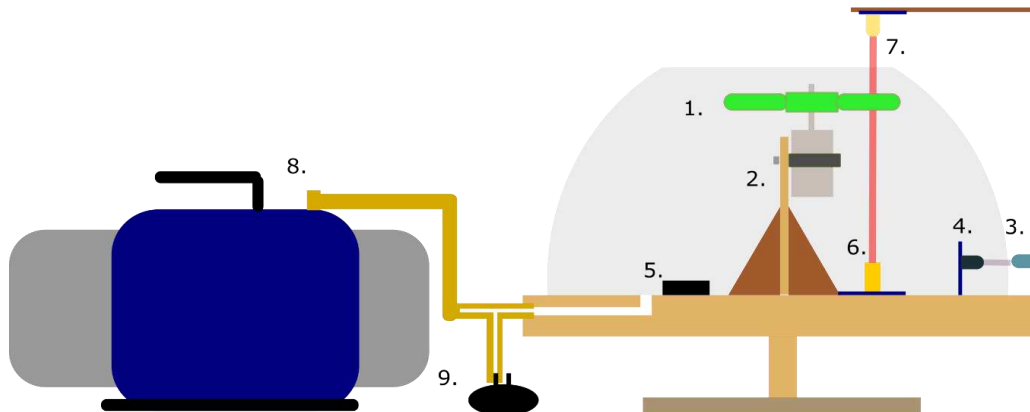


**Figure 1.a**: Structure of the measurement setup. Legend: 1. fidget spinner, 2. DC motor mounted on a stand, 3. infrared transmitter circuit, 4. infrared receiver circuit, 5. batteries 6. laser diode module 7. phototransistor circuit (6 - 7. combined: photogate), 8. vacuum pump, 9. pressure sensor[1]
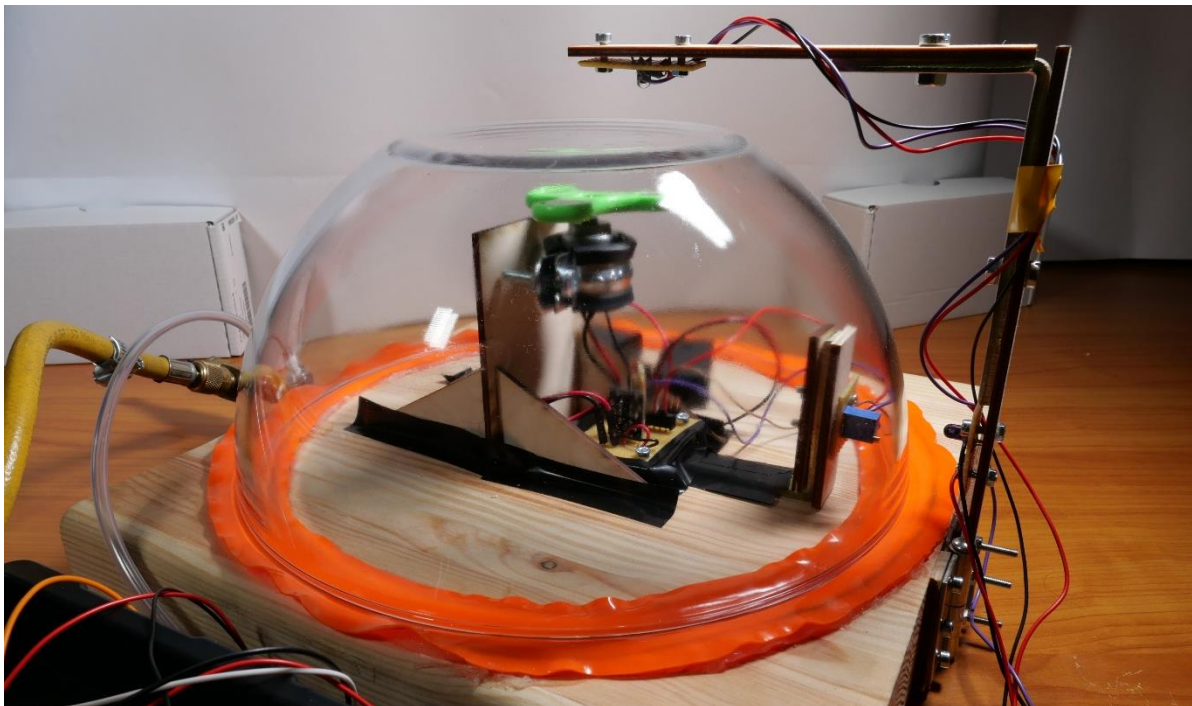


**Figure 1.b**: Photo of the measurement setup

## 3.2. Electronic implementation of measurement tasks

We also designed custom electronics for our measurement setup. Tasks to be solved were

   a) Power supply to the motor that drives the fidget spinner
   b) Power supply to the laser diode and the transistor switching the motor

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[1] Figure was made in Inkscape.

c) Control of the IR transmitter and receiver opening the transistor
d) Detecting the signal of the photogate
e) Measuring the pressure.

### 3.2.1. Sensors and converters

In the process of digital signal processing, sensors that convert physical signals into electrical signals and devices that convert analogue electrical signals into computer-readable digital signals are indispensable. Their roles are illustrated in Figure 2 [16].
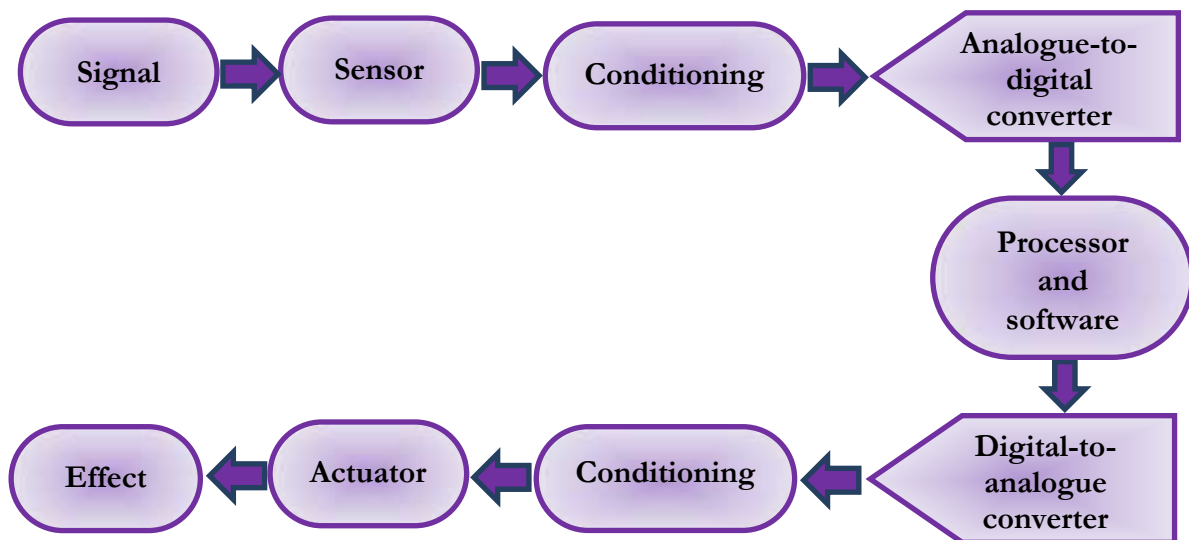


**Figure 2**: Process of digital signal processing

During the measurement, an MPX 4250DP type pressure sensor was connected to the vacuum hose with valve. . This is a so-called differential, calibrated sensor that tracks the pressure in the vacuum chamber in comparison to the outside air pressure [17]. As mentioned above, for motion detection the self-assembled photogate consisting of a KY-008 laser module and a phototransistor was applied [18], [19].

The sensors and circuits performing the listed measurement tasks were connected to two types of measurement devices (myDAQ, Arduino UNO), which play an analogue-to-digital converter role among others in our measurement process.

### 3.2.2. Signal measurement with a myDAQ

The measurement was performed with a multifunctional device called myDAQ (DAQ stands for Data Acquisition), which was developed by National Instruments directly for school laboratory measurements. On the device two analogue input (AI) and two analogue output (AO), eight digital input / output (DIO), one audio input and one output connector, and digital multimeter (DMM) connectors can be found. Power to the instrument is provided via USB port, just like the bidirectional communication between the instrument and the computer controlling data logging and transferring to the measured data [20].

In the first version of our measurement, the photogate signal was measured on the AI1 analogue channel at a sampling frequency of 100,000 samples per second. As one of the arms of the toy passes through the photogate, the measured voltage changes from ~ 0V to ~ 5V. When the angular

velocity of the motor-driven fidget spinner is 110 $\frac{rad}{s}$, a voltage switch occurs in every 19 ms, and due to the deceleration, growingly longer periods of time can be measured. As a result of the measurement, an analogue rectangular signal characterized by an increasing pulse width is obtained.

The pressure was measured on the AI0 analogue channel of the myDAQ at a sample rate of 1000 samples per second. The advantages of measuring an analogue signal are that we can see the waveform, we constantly sample it, and the hardware controls reliable timing. Circuits constructed to perform the previously listed measurement tasks (a-e) and connected to the myDAQ are shown in Figure 3.
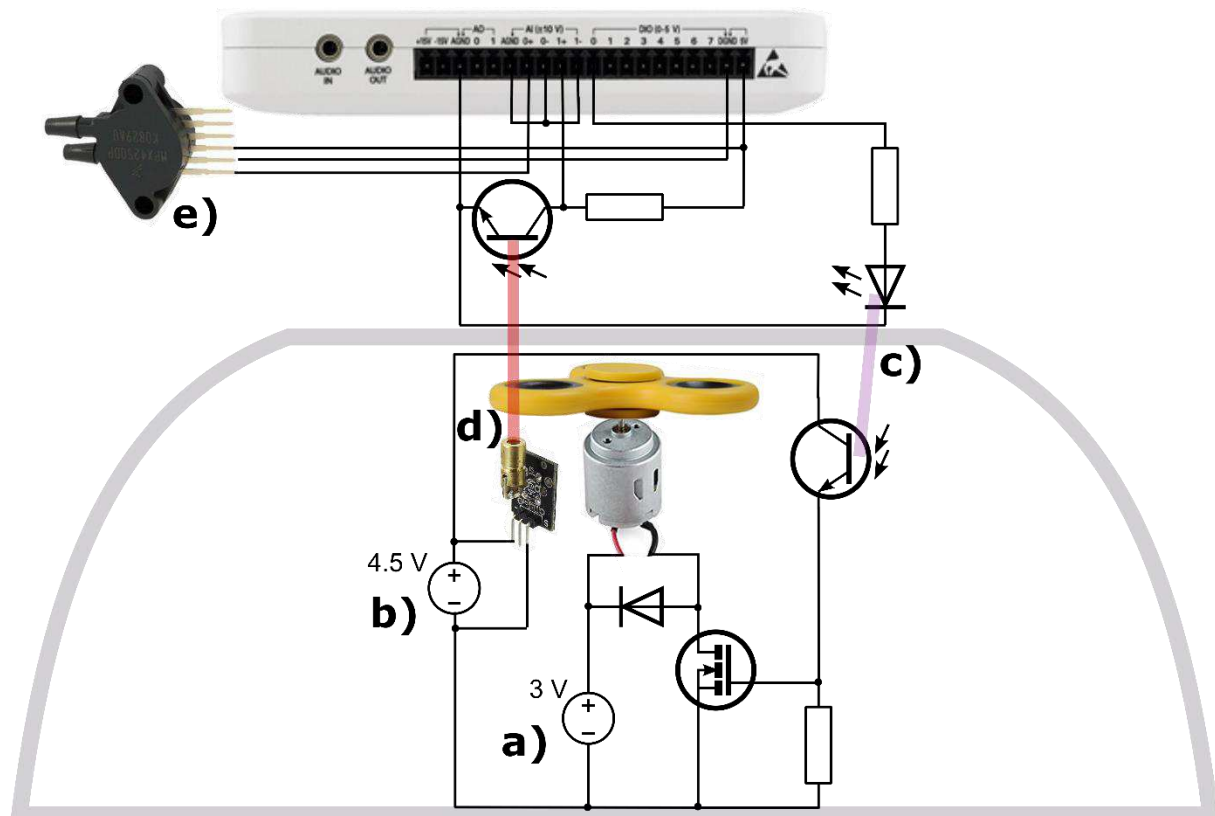


**Figure 3**: Wiring diagram of the circuits connected to the NI myDAQ device. In the lower and upper half of the figure, the circuit inside and outside the vacuum chamber is shown, respectively[2]

### 3.2.3. Signal measurement with an Arduino

The NI myDAQ is specifically designed for student experimentation, also considered very user-friendly in many ways, however, it is relatively expensive to acquire. Although, to our knowledge, myDAQ is available in a growing number of Hungarian secondary schools through various competitions and grants, we present a modified version of our measurement using an Arduino as well. The popular, reasonably priced, open-source and easily obtainable platform could, in

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[2] Figure was prepared in Inkscape. Sources of used images (Last retrieved 23/04/2020):
https://images-na.ssl-images-amazon.com/images/I/71aDevQIaZL._SL1500_.jpg
https://images-na.ssl-images-amazon.com/images/I/41V-87Kw50L._SX342_.jpg
https://bestcustomflashdrives.com/wp-content/uploads/2017/08/Custom_Fidget_Spinners_sideview.jpg
https://i.ebayimg.com/images/g/FyoAAOSw60NbQwea/s-l1600.jpg
http://k12lab-support-pages.s3.amazonaws.com/LVEduTutorialsCSS/images/mydaq_sideview.gif

principle, be applied to measure *an analogue signal* in the same way as the myDAQ. However, the maximum sample rate is far below that of the device already described, less than 10,000 samples per second. Therefore, in our measurement with Arduino, the signal of the gate was switched to a digital channel and observed when the signal jumped from a logical low to a logical high, that is, when an arm of the spinner intersected the light path. Figure 4 illustrates how circuits connected to an Arduino UNO board can be assembled using a breadboard, e.g. for testing purposes. (The measurement tasks are indicated as in Figure 3.)
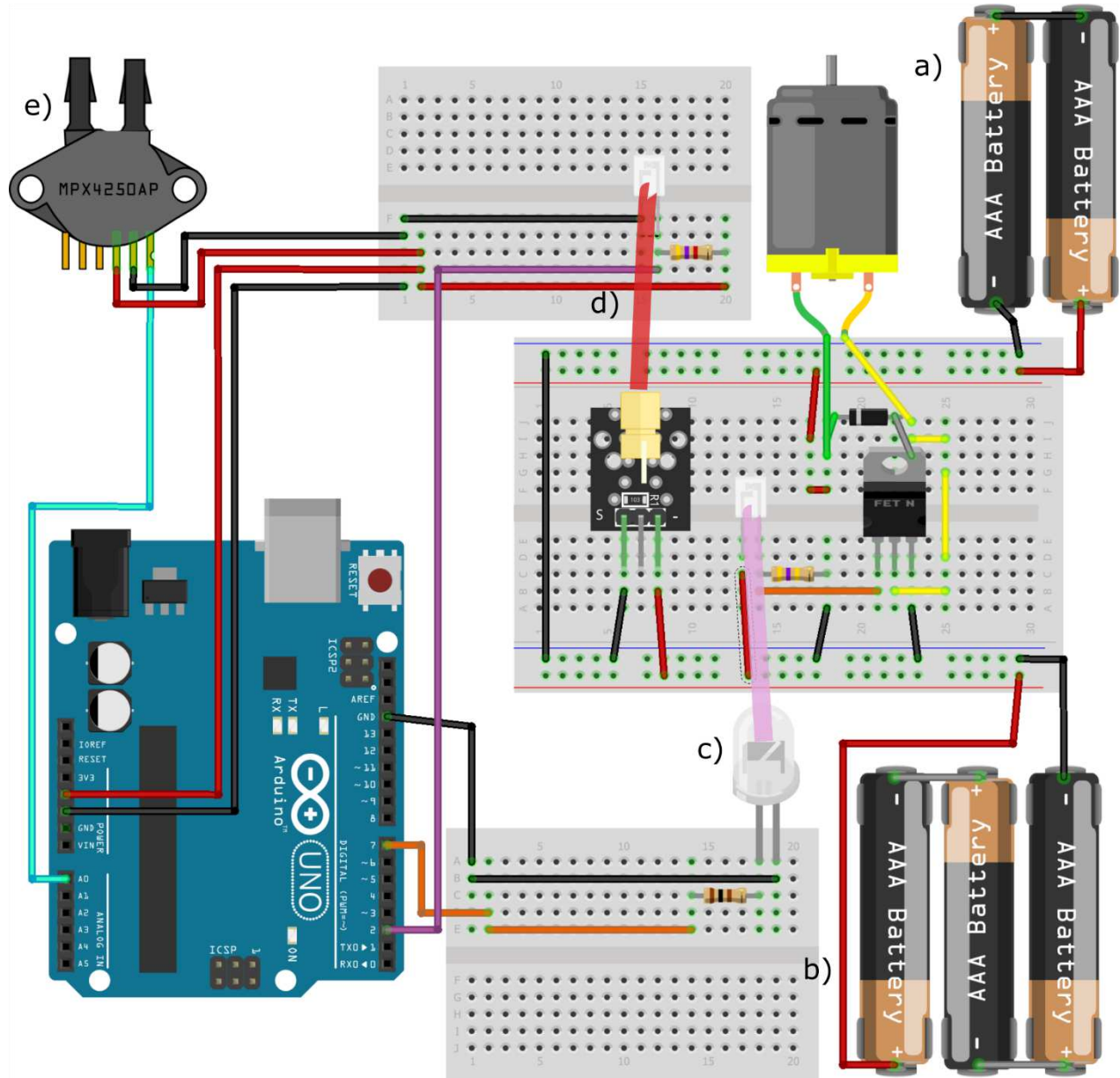
**Figure 4**: Building of circuits connected to an Arduino UNO on breadboards[3]

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[3] Figure was made in Fritzing.

# 4. 'Software' used in the measurement

Programming the two devices described above is quite a different. MyDAQ is programmable in the LabVIEW graphical programming language, while Arduino is programmed in a C/C++ -based environment or even in Python or other text-based programming languages. The applied software solutions for these two devices are also radically different because of the difference between evaluation of analogue and digital signals, measured by the myDAQ and Arduino, respectively, based on the arguments above.

## 4.1.   Programming LabVIEW for the myDAQ

### 4.1.1. LabVIEW graphical programming environment

LabVIEW has been mainly developed for controlling industrial computer-driven measurements and for processing and evaluating measurement results. Programs written in LabVIEW are commonly referred to as virtual instruments (.vi), the two main parts of which are the Front Panel resembling a dashboard and the Block Diagram containing the program code. In the Front Panel, control fields (e.g. buttons, drop-down fields) and indicator fields for the user (e.g. numerical or string fields, graphs) can be displayed. In the Block Diagram, graphical objects can be placed that represent built-in functions, connected to each other by data lines, and arranged into different program structures. An important principle of the language is the so-called Data Flow: an instruction is executed in the program when it has received the required signals for all its inputs. In this way, the commands can be chain-linked in order to determine their execution order [21].

The NI-DAQmx driver is usually used to program the DAQ devices of National Instruments for configuration, data measurement and generation tasks according to our needs. The function library of the driver includes, among other things, creating, reading and writing a virtual channel, as well as starting, stopping and timing a task, etc. [22]

### 4.1.2. Solution of the producer-consumer problem in LabVIEW

The essence of the classical *producer-consumer synchronisation problem* i.e. two processes, the producer creating objects and putting them into a fix-sized *buffer*, and the consumer extracting and using data from the buffer are handled by the program. When the buffer is empty or full of data, one of the processes must wait. In our analogue measurement with the myDAQ the producer takes samples at determined intervals (in case of 100,000 samples/s the period is 1 μs) and places this data in a buffer for storing 100,000 samples.

A queue data structure is used to implement the first in first out (FIFO) principle, that is, whichever data comes first, leaves first. Before running the producer, the queue is created, and the producer fills it with 10,000 voltage values per cycle. Tasks of the consumer process in our virtual instrument are to retrieve the measured voltage signal from the queue, to return time interval between data points, then to arrange data series into arrays and finally to write it into a data file. Due to this solution, real-time measurement at equal intervals is not interrupted by the storage and processing of data.
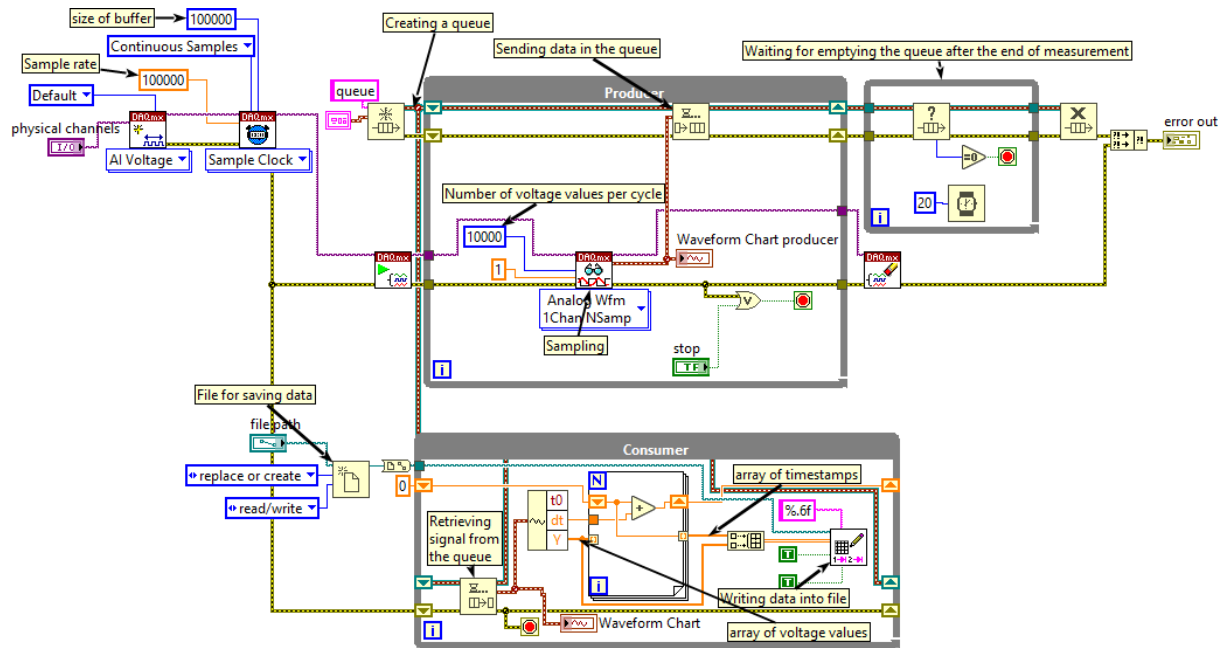
**Figure 5**: Block diagram of the LabVIEW virtual instrument for measuring the signal of the photogate

### 4.1.3. Postprocessing or live data streaming in LabVIEW

After completing the measurement driven by the virtual instrument described above, the measured data separated by tabulator characters are stored in a .txt file. The data can then be processed in a simple spreadsheet software or in LabVIEW, too. The first task is to perform a level crossing detection in the rectangle signal, that is, to find timestamps when the photogate signal has a jump and to collect them in an array. Between these periods, the fidget spinner moves 120°, and from its increasing rotation angle we also build an array with a for loop. This pair of arrays arranged in a cluster, i.e. rotation angle as a function of time can be plotted on an XY graph. It is also possible to visualize the results of more measurements on the same graph.

About physical changes it could be more informative to look at the speed of change. Let $\alpha_i$ and $t_i$ denote the i-th element in the arrays of rotation angle (in radians) and timestamp, respectively.

$$\omega_i \approx \frac{\alpha_{i+1} - \alpha_i}{t_{i+1} - t_i}$$

Here, in fact, we calculate the value of the difference quotient, also called the forward numeric derivative. By performing the operations on the elements of arrays, a shift register can also be used to form an array of angular velocity and after clustering these values can be plotted as a function of time, illustrated in Figure 7. A great advantage of LabVIEW is that our graphical code of data postprocessing could be transformed and transported into the consumer process, and this way a near real-time graphical data representation would be implemented. This live data stream can be an excellent tool for demonstrational experiments in a classroom.

### 4.2.  Programming embedded software for Arduino

Two software programs need to be discussed when using the Arduino platform. First, there is a code running on the microcontroller, written in C/C++. Data are transferred to the PC via USB serial port using a simple protocol: traverses of the fidget spinner in front of the phototransistor

are continuously detected and the timestamp (in the form of integers) of these events are sent. Each message is closed with a comma and a line break. Second, there are several ways to receive data on a host computer. We present three simple options for this in the rest of the chapter.

### 4.2.1. Implementation of data logging using an Arduino

While in case of the myDAQ, measurement is controlled by the LabVIEW software running on a computer, we need to implement an embedded software when using an Arduino, though. The purpose of this software is to measure the incoming signals and then send the received data to the computer through serial port. For the implementation, we searched for software tools that are well known and compatible with all Arduino boards (so we did not apply direct writing and reading of registers). There is no way to sample analogue signals as quickly on an Arduino as with a myDAQ. However, the signal we want to measure is digital: the fidget spinner either intersects the path of light or not. Because of this, it can be directly measured through a digital input. Yet, care must be taken to ensure that the signal levels measured at the output of the phototransistor are within the voltage range sensed by the Arduino.

When precise and accurate time measurement is required, the best way is to use interrupts [23]. The Arduino can receive external interrupts where the interrupt servicing routine can be set to be called for the rising edge (switching from 0 to 1). To query the time within the routine the micros() function can be used which returns the elapsed time from the start of the microcontroller in microseconds (μs) as a 32-bit number. This will be used as a timestamp to track events. The actual resolution of the timestamp may vary depending on the specific platform, with 4 μs for the currently used Arduino UNO. In addition, there may be some uncertainty in the time when exactly the interrupt routine would be executed but overall, the error will be less than 10 μs. This way the Arduino can be better than the previously used myDAQ. In addition, there may be some uncertainty in the time when exactly the interrupt routine would be executed, and the slew rate of the rising edge can also introduce timing errors. Depending on the rise time of the photogate signal, the error can be less than 10 μs this way the Arduino can be better than the previously used myDAQ.

Although we talk about a single-core system, because of the use of interrupts as a kind of time-sharing system, we have multiple processes running. Therefore, secure data transfer between processes is critical. First, the variables involved must be declared as volatile, so they will certainly not be cached in any register. Second, since a timestamp is 32 bit long, that is 4 bytes, its copy is not an atomic operation. Therefore, interrupts are disabled in the main program (loop) for the duration of the copy. Finally, data are transferred to the PC via USB serial port at a 115200 bit/s baud rate.

### Program code

```
// Digital input for time measurement
#define INT_PIN 2
// Detected: Rising edge
#define TYPE RISING

volatile unsigned long timeIsr; // temporary variable to safely pass the timestamp value
unsigned long timeTmp; // temporary variable to store timestamp value temporarily
unsigned long timePrev = 0; // previous value of the timestamp
unsigned int timeOutCounter = 0; // timeout counter

/* Initialization, after starting the microcontroller, it runs once */
void setup() {
  pinMode(INT_PIN, INPUT); // Configuring digital input for time measurement
```

```
  attachInterrupt(digitalPinToInterrupt(INT_PIN), isr, TYPE); // Assigning interrupt to
digital input
  Serial.begin(115200); // Setting up Baud Rate of Serial port
  while (!Serial) {  ;  } // Waiting for connection (in case of USB devices with native USB
ports)

}

/* Main loop, repeated as an infinite loop. */
void loop() {
  noInterrupts(); // Denying interrupts in order to pass the timestamp value safely
  timeTmp = timeIsr; // Copying timestamp in the temporary variable
  interrupts(); // Allowing interrupts again
  if (timePrev != timeTmp) { // When the previous timestamp is not equal to the current one:
there is an event!
    timePrev = timeTmp; // Refreshing stored timestamp
    Serial.print(timeTmp); // Sending the timestamp
    Serial.println(","); // Sending the delimiter
  }

  delay(1); // Waiting for a little time
 }

/* Interrupt service routine. */
void isr() {
    timeIsr = micros(); // reading timestamp
 }
```

The above code is relatively simple, but it only performs time measurement. If a real-time value of the pressure is also required, the program must be supplemented with the measurement and transmission of the analogue signal. If you want to measure pressure even when the fidget spinner is not spinning, the data transmission protocol must be more complex. The Arduino is capable of controlling the motor by switching on or off a digital output depending on the control message received from the computer. The description of implementing these two tasks is beyond the scope of the article, but the code is available in the attachments of the article [24].

### 4.2.2. Receiving data from an Arduino using Excel Data Streamer

One of the development teams of Microsoft Garage created a free add-in for Microsoft Excel designed directly for educational purposes and for student measurements [25], [26]. Data Streamer can be downloaded from Microsoft's website or enabled in Office 365 among COM extensions. For the former, the add-in will appear in the header of the Excel file as 'Data Streamer'. The application should be customized according to our requirements. On the 'Connect a Device' tab, the appropriate communication port or device needed to be selected, in this case an Arduino UNO. Worksheets in Excel for Data in, Data Out, and Settings will be then automatically displayed. In the latter, you can, among others, set the time interval between incoming data to 10 ms-10 s, the number of channels, and choose whether the most recent data would be written in the last or first cell of the displayed data column. The default number of data rows that can be displayed is 25, which in the current version of Data Streamer can be increased to a maximum of 500. Then, in Advanced settings, the communication rate (baud rate) must be set in the same way as it is used in the measurement when its value is different from the default value of 9600 (in our case 115200).

The measurement can be started with the Start Data function. As a result, the data will be displayed in the Data In worksheet. The data can be stored by pressing the Start Recording and then the Stop Recording button, after which a pop-up window is displayed making it possible to save the data in CSV format. It can later be imported into a spreadsheet program for further evaluation. It may be useful for example to make the measured data available to the students and let them perform

numerical derivation (calculate the rate of change) as an individual task. Of course, when real-time evaluation of the measured data for classroom demonstration purposes is required, a standard cell reference on a new worksheet could be a useful tool. The problem, however, is that (in the current version of the add-in) the number of displayed data rows cannot be increased to more than 500, so when more useful pieces of data come in through the channels, finding another way to collect data is necessary.

We provided an obvious solution to the problem with the help of an Excel VBA macro. This short program monitors the cell in which the most recent data is displayed and when its value changes, exports the content of this cell and writes it at the bottom of a specified column. Thus, the collected timestamps are listed in chronological order in the corresponding column of our worksheet used for evaluation.

### Excel VBA macro:

```
Private old As Long
Private Sub Worksheet_Change(ByVal Target As Range)
   Dim KeyCells As Range

   Set KeyCells = Range("B5")

If Not Application.Intersect(KeyCells, Range(Target.Address)) _
       Is Nothing Then

      v = Range("B5").Value Worksheets("Data In").Range("B5").Value
      If old <> v Then
         LstRw = ActiveCell.Row + 1
         Range("F" & LstRw).Select          Cells(LstRw, "F") = v
         old = v
      End If
End If
End Sub
```

Our Arduino measurement program, presented earlier, reads the event timestamps in microseconds. It is advisable to work in seconds and to fix t = 0 at the time the first data arrives (the first element of column A) by the formula

```
IF(A3=0;" ";(A3-$A$2)*10^(-6))
```

Excel can be pre-set to calculate the angle of rotation in another column of the evaluation worksheet by the formula

```
IF(A1=0;" ";(ROW(D1)-1)*2*PI()/3)
```

If a timestamp has already appeared in a given row, we add $\frac{2\pi}{3}$ (=120 °) to the value from the previous row.

A column is also devoted to numerical derivation, i.e. angular velocity calculation. By the

```
IF($A1=0;" ";2*PI()/3/($B2-$B1))
```

formula the first element of the column can be calculated.

Obviously, in addition to the current received timestamp, an undefined field will appear in the angular velocity column, which will be interpreted only when the next timestamp is received, this way the current value of the angular velocity is always determined in a step disadvantage.

By selecting the appropriate columns to create an XY-diagram that would be updated according to the available data, the rotation angle and the angular velocity over time can be monitored in real-time.

### 4.2.3. Receiving data from an Arduino using a LabVIEW program

The data sent by the Arduino board through serial port can also be received and processed by LabVIEW. The advantage of LabVIEW is that the program can be easily supplemented with further data processing. The created relatively simple LabVIEW program code with detailed comments is shown in Figure 6. The program constantly monitors the serial port and in case of message arrival tries to interpret it. If the message format is valid, it stores the data in an array (the timestamps of events and the time difference between events). The stored data can be displayed on a graph or saved to a file. The saved data can later be processed by any program. This program is available as a LabVIEW source code and as an executable that can be run without the LabVIEW development environment, as well. Extra functions mentioned before (continuous pressure measurement, motor control) can also be implemented in LabVIEW, the source code of which is attached to the article.
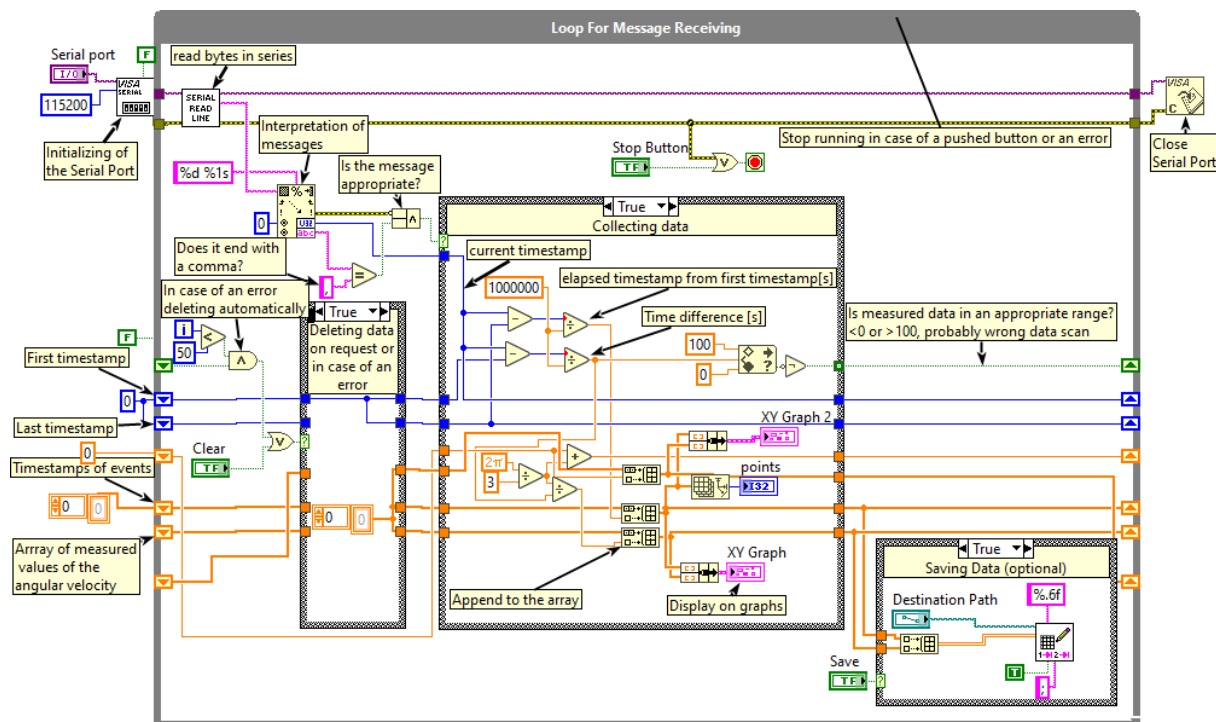


**Figure 6**: Reading data received through Serial Port in LabVIEW

### 4.2.4. Receiving data from an Arduino using a Visual C based program

Beside the two ways described in the previous parts of the article, with the aim of processing measurement data on a host PC coming from an Arduino, a self-developed program was developed in Visual C.

It receives, evaluates and stores CSV data in real-time coming from an Arduino board. In offline mode, it is capable of simulating the phenomenon and analysing it time after time.

## 5. Results and discussion

Based on our measurement results, our question in the problem identification might finally be answered. The graphs in Figure 7 display the rotation angle and the angular velocity of the fidget spinner as a function of time. The results of five measurements at normal atmospheric pressure and five control measurements at 17% vacuum (17 kPa) are compared. Starting points of the data series were aligned with each other so that the decrease from the $110 \frac{rad}{s}$ angular velocity was plotted from the start time of t = 0 s.
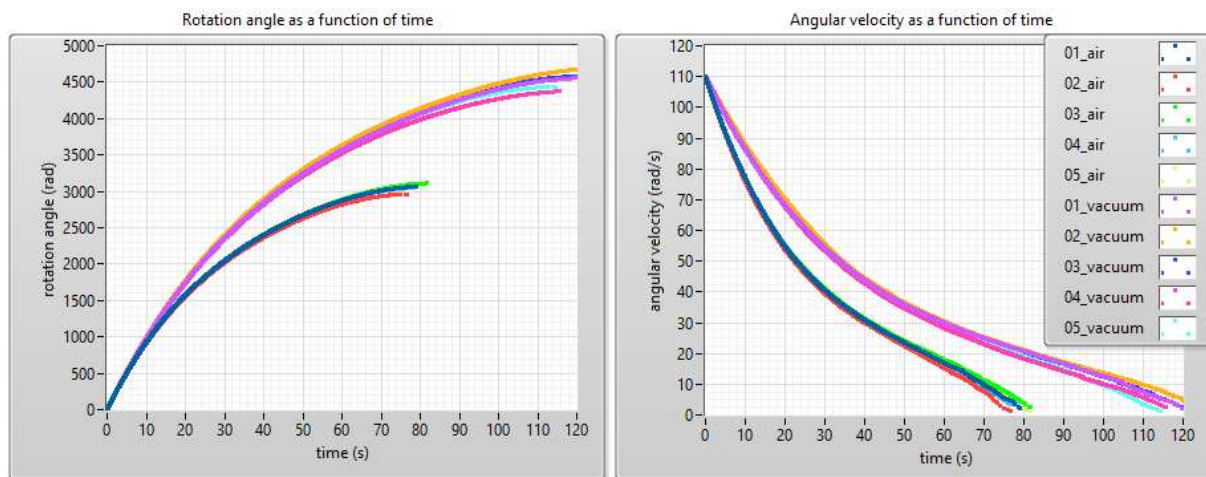


**Figure 7**: Results of our measurement in 17% vacuum and in normal air pressure

Comparing the graphs, it can be seen that starting from the same speed, free rotation takes about 40 seconds longer under vacuum. This suggests that air drag was involved in braking the movement of the toy. At the same time, there is a significant braking effect in vacuum, which is caused by the time-dependent friction of our bearing. The nonlinear decrease in angular velocity, even in vacuum, may indicate that friction is velocity-dependent, which may be a surprising statement for those who are aware of high school physics. Further measurements are needed to get around the problem correctly (see Chapter 6). Measuring the moment of inertia of the fidget spinner and examining the change in angular acceleration over time would reveal the supposed speed dependence of the friction torque, but other factors, such as the possible temporal change in operating temperature, may also be partly responsible.

## 6. Future research steps

In our paper we have presented a possible measurement method for solving wireless signal transmission with an optical signal, either for controlling circuits in a vacuum or for measuring the signals there. Our goal is to improve our system so that it is suitable for school use, that is why we need to take into consideration more issues that may arise.

The first is that in some schools vacuum chambers and pumps are already available, so only a pressure sensor is needed to be connected to the equipment. However, if the connectors do not meet current standards, the task becomes complicated. It may therefore be desirable to use an absolute pressure gauge (instead of a differential one) and to place it inside the vacuum chamber. Another possible aggravating circumstance is the effect of the chamber wall on the optical signal. Thick glass material partially absorbs the laser light, often with light scattering, and when the light path is not perpendicular to the glass interface, the glass refracts the beam of light. All these make

it difficult to detect the laser light and set the phototransistor properly. This problem can also be solved by placing a photogate inside the chamber.

However, if this is the case, it must be solved for both sensors to transmit their signal outside the vacuum chamber. Data transfer through electrical wires is not advisable as it would be required to prevent airflow at more places in the chamber. It is also a possible choice to place a microcontroller in the vacuum chamber so that the pressure sensor and photocell signal can be measured locally and even the motor circuit could directly be switched. Obviously, there is a need to choose a device that can wirelessly transmit measured data, such as an Arduino-compatible ESP32 chip capable of Bluetooth and Wi-Fi communication [27] .

We also plan to further validate the results. The bearing of the game can be replaced by one with known catalogue information, e.g. by an SKF bearing so that the radial and axial forces acting on the bearing during movement could be determined [28]. With this information available, according to a bearing model developed by SKF, the parameters of a given type of bearing can be used to calculate the frictional torque acting on a bearing as a function of its rotational speed. When the angular acceleration β (the second derivative of the rotation angle) from the remeasured kinematic properties of the modified fidget spinner would be determined, and the mass moment of inertia (θ) describing the mass distribution would be measured, their product, the total braking torque ($\sum$M) could be given as a function of speed according to the basic equation of rotational motion ($\sum$M = θ · β). This would allow comparison of theoretical and measured values.

## 7. Educational experiences

Previously three competitive essays were made at the Radnóti Miklós Experimental High School in Szeged, Hungary to take part in a competition arranged by Eötvös Loránd Physical Society and National Instruments Hungary Kft. with the aim of encouraging physics teachers and students to use and program a myDAQ device in LabVIEW [29]. The core of this study was also included in the project Repetition is the Mother of all Learning - Generation and Evaluation of Periodic Signals by Anikó Somogyi, Kornél Kovács and Katalin Balog. The authors of this study hold a weekly myDAQ course at school and a twice-weekly programming course. The presented measurement was carried out with a simpler experimental setup in smaller (three persons), then larger (ten persons) groups, and was used as a classroom demonstration experiment as well. Some of the members of the Research Group of Technical Informatics Methodology are high school teachers themselves. The team has published a number of tested measurements developed for Edaq530 and Arduino over the past decade [6], [15], [23], [30],  [31], [32].

## 8. Conclusions

Technical informatics can create a natural connection between informatics and physics. In our experience, it is worth adopting measurements in the classroom as it is useful in teaching programming beyond its motivational role. In this article, we have provided effective solutions for performing a specific measurement and evaluating the data, which can be utilized for other measurements as well. In order to achieve this, the source codes are attached to the study.

## Acknowledgement

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## About this document

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# Supervised Learning Methods for Skin Segmentation Based on Pixel Color Classification

TAAN Ahmad, FAROU Zakarya

**Abstract**. Over the last few years, skin segmentation has been widely applied in diverse aspects of computer vision and biometric applications including face detection, face tracking, and face/hand-gesture recognition systems. Due to its importance, we observed a reawakened interest in developing skin segmentation approaches. In this paper, we offer a comparison between five major supervised learning algorithms for skin segmentation based on the color of individual pixels in images. The algorithms involved in this comparison are: Support Vector Machines (SVM), K-Nearest-Neighbors (KNN), Naive Bayes (NB), Decision Tree (DT), and Logistic Regression (LR). Various scenarios of data pre-processing are proposed including a conversion from RGB into YCbCr color space as well as duplicated records dismissal. Using YCbCr representation gave a better performance in skin/non-skin classification. Despite the settled comparison criteria, KNN was found to be the most desirable model that provides a stable performance overall the several experiments conducted.

**Keywords**: Supervised learning methods, Pixel-based skin segmentation, RGB color space, YCbCr color space.

## 1.    Introduction

Skin segmentation is an essential topic that aims at segmenting regions in an image which refer to skin for further processing. It is broadly used in diverse aspects of computer vision and biometric applications, including face detection, face tracking, and face/hand-gesture recognition systems. Segmentation methods can be pixel-based where only individual pixels are examined without considering neighborhood pixels or region-based. Various image attributes can be used for skin segmentation, one of these to consider is color. Indeed, by investigating the skin dataset which is collected by a random sampling of RGB values of face images of various age groups (young, middle, and old), community groups (white, black, and Asian), and genders, we found that skin color can be solely applied to identify skin regions from its neighborhoods for a given image. Among the total amount of available examples, roughly 0.02% were perceived common amid skin and non-skin pixels. That means that color is a distinctive characteristic of skin, which will result in very high segmentation accuracy if applied judiciously.

To address this issue, we can adopt different approaches. For instance, due to the small region of the intersection between skin and non-skin in color space, it is conceivable to think of deriving mathematical formulas for both regions, then substituting RGB values with formal equations. Thereby, the categorization of skin and non-skin pixels would be simple, however, due to the complex relationship between RGB values, it might be impossible to represent skin and non-skin pixels by explicit formulas. Even though mathematical relations sound to be simpler, we observe a similar situation when transforming RGB values into YCbCr color space. Considering a novel transformation for this situation is worth to try. However, in this paper, we consider another approach where we employ machine learning (ML) or more precisely supervised learning methods (SL). As each SL algorithm possesses pros and cons and that the performance of SL algorithms depends on the concerned problem, we aim to examine the performance of five major SL algorithms for skin segmentation.

The rest of the paper is structured as follows. In Section 2, a decent review of five major SL methods, color spaces as well as related works are presented. Afterward, the dataset is explored extensively via illustrative graphics in the first part of Section 3. Then training the models for

various cases are handled in the second part of Section 3 alongside the specification of the hardware and runtime environment used for the conducted experiments. Evaluation metrics and achieved results are discussed with graphics and comparative tables in Section 4. Last, but not least, in Section 5 we conclude the paper by suggesting possible future works.

## 2.    Background

Machine learning (ML) [1] is a form of artificial intelligence that enables a system to learn from data rather than through explicit programming. As described in Figure 1, ML can be divided into three subgroups: supervised learning (SL), unsupervised learning (UL), and reinforcement learning (RL). In SL methods, both data and its desired label are used as input during the training process, which will allow the machine to learn from the data and produce a model. However, in UL methods where no labels are provided, an algorithm is applied to extract to the similarity among input data, regroup them inside a group and extract the clusters to efficiently classify new data. Other possible applications of UL would be to study the density estimation of input data which is diffused in latent space. The last type of ML is reinforcement learning, RL is a more advanced ML that allows an agent to learn in interactive conditions by trial and failure using feedback of its actions and experiences.
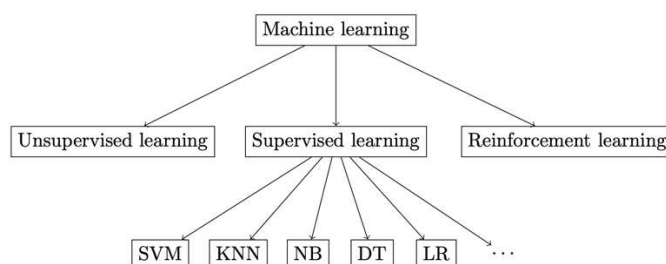


**Figure 1**: Types of ML

In this paper, we are considering only a subset of SL methods. The subset contains five classification techniques: Support Vector Machines, K-Nearest-Neighbors, Naive Bayes, Decision Tree, and Logistic Regression. As it is important to understand the methods that we will use during our experiments, a brief review of the methods is given in the next subsection.

### 2.1.    Supervised Learning Methods

#### 2.1.1. Support Vector Machine

Support Vector Machine (SVM) [2][3] is a SL algorithm proposed in the 1990s and used mainly for pattern recognition, and more often for classification problems. As described in Figure 2, a linear SVM attempts to divide a given dataset into two separate classes by finding the best hyper-plane. A hyperplane could be interpreted as a line that linearly separates and classifies a set of data in case, we are dealing with a dataset with only two features. The further away the data points are from the hyper-plane, the more reliable and accurate the model will be. We therefore want our data points to be as far away from the hyper-plane as possible, but still on the correct side of the hyper-plane.

Support vectors (instances with green color in Figure 2) are the closest elements to the hyper-plane and the most important data points of a dataset. Excluding support vectors would change the position of the dividing hyper-plane and reduce the chance of correctly classifying new data. If no data points are linearly separated, they are projected into a higher dimension. In 2D the hyper-plane was a line, therefore in 3D the hyper-plane becomes a surface. The mapping of data into a higher dimension is known as *kernelling*. [5]
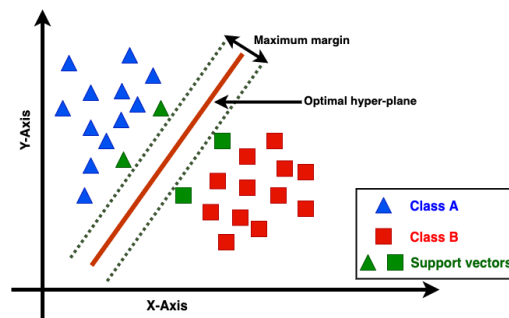


**Figure 2**: Linear SVM classifier with a hyper-plane

### 2.1.2.   K-nearest Neighbors

K-nearest neighbors (KNN) is a lazy learning algorithm [3], which is often used for classification tasks. It is one of the easiest classification algorithms to understand. Despite its simplicity, it can still deliver very competitive results. KNN is based on similarity measurements between dataset instances, where *K* is a critical hyper-parameter for this algorithm, indicating how many nearest neighbors we should consider for the classification of a new instance.
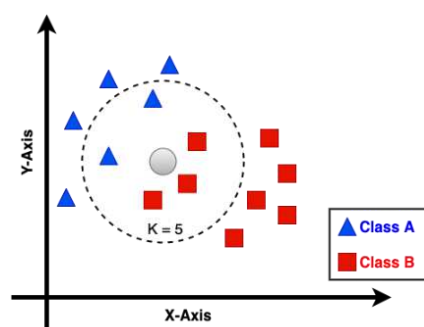


**Figure 3**: An Example of KNN Algorithm where *K=5*

For example, if we have two classes: squares and triangles (as described in Figure 3) and we fix *K*=5. With a new instance (circle) and based on the *K* parameter, the circle will be classified as a square, because the majority of its neighbors (in this case 3 of 5) belong to the same class. This means that the new instance is more likely to be a square than a triangle.

### 2.1.3.   Naive Bayes

Naive Bayes (NB) [3][4] is a classification algorithm for binary (two-class) and multi-class classification problems that uses the Bayes' theorem. Bayes' theorem provides a way that we can

calculate the probability of a piece of data belonging to a given class, given our prior knowledge. Bayes' Theorem is stated as:

$$P(y|X) = \frac{P(X|y) \times P(y)}{P(X)} \tag{1}$$

Where $P(y)$ is the prior probability of $y$, $P(X)$ is the evidence of $X$, $P(y|X)$ is the probability of a class given the provided data, $y$ is the class label, and $X$ is a dependent feature vector of size $N$ where:

$$X = (x_1, x_2, x_3, \dots, x_N) \tag{2}$$

The technique is the easiest to understand when described using binary or categorical input values. It is called *Naive Bayes* because the calculation of the probabilities for each hypothesis are simplified to make their calculation tractable. Rather than attempting to calculate the values of each attribute value $P(x_1, x_2, x_3|y)$, they are assumed to be conditionally independent given the target value and calculated as $P(x_1|y) \times P(x_2|y)$, and so on.

### 2.1.4. Decision Tree

A decision tree (DT) [3] has a structure that looks like a flowchart graph where each inner node has a threshold-based test for a specific feature, each branch represents the outcome of the test, while leaf nodes represent class labels. The entire path starting from root until reaching the leaf represents classification rules. Tree-based learning algorithms are considered to be one of the best and mostly used supervised learning methods as they offer models that are highly accurate, stable and easily interpreted compared with black-box models such as neural nets as they are very close to human logic.

### 2.1.5. Logistic Regression

Logistic Regression (LR) [6] is mainly used for binary classification problems, LR is a predictive analysis algorithm based on a linear regression model which uses a complex cost function. The cost function used for LR is called Sigmoid function $\sigma$, which is known as the logistic function, hence the name of logistic regression. $\sigma$ is used to map predicted values (class labels) to probabilities, it means that given any real number, applying the sigmoid function on it will give a new value between [0...1]. The sigmoid function is defined as the following:

$$\sigma(x) = \frac{1}{1 + e^{-x}} \tag{3}$$

Such a classifier uses a decision boundary. A decision boundary in case of LR for binary classification problems is a fixed threshold value. Based on the threshold value, LR algorithm gives a class label to the probabilities calculated with $\sigma$. For Example, if we have 2 classes that has 0 and 1 as labels, a threshold $\varphi$, and a new instance $d$, we give a class label $y$ to $d$ by using the following rules:

$$y_d = \begin{cases} 0, & \sigma(d) < \varphi \\ 1, & \sigma(d) \geq \varphi \end{cases} \tag{4}$$

## 2.2.    Related Works

Many researchers have addressed the problem of skin segmentation in their studies. Each providing different algorithms and aspects to deal with the problem. Some of them focused on color models to improve skin detection accuracy, whereas others argued it is not related to color model selection. For example, in [7][8][9][10] they adopted the RGB or normalized RGB color models for skin color modeling. Whereas YUV was selected in [11]. YCbCr which is adopted in our study was used also used in [12] and [13]. In [14], they conducted a comparative study between the color spaces (Normalized RGB, YCbCr, Fleck HS, CIE Lab, and HSV) for skin detection. In [15], the authors argued that color space does not contribute to skin segmentation accuracy. They tried to prove this fact in their comparison between RGB, YCbCr, and HSV color spaces. They explained that an optimal skin model can be achieved for each color space.

Apart from color spaces, diverse methodologies are present in literature for skin segmentation. Some methods rely on statistics and probability concepts, such as probability distribution functions, distance-based methods, and look-up tables. However, an attempt to build a skin Gaussian model with CgCr color space was studied in [16]. In [17], the authors used look-up tables of skin color probabilities, where mathematical calculations do not take place in the skin detection process, so they perform much faster than other methods. On the other hand, distance-based approaches need to calculate distance equations for each pixel in an image to classify pixels into skin and non-skin. This makes execution time drastically higher. Such a method was adopted by [18].

Other methods involve ML (similar to our paper), where the model is trained on the skin segmentation dataset and then tries to classify new pixels into skin and non-skin. For instance, SVM and convolutional neural networks (CNN) were adopted to detect skin regions in [20] and [19], respectively.

As a result, in this paper, we are considering the usage of various color spaces (RGB, YCbCr, and CbCr) alongside SL methods (previously described in Section 2.2.) for the classification of skin segmentation dataset [21].

## 2.3.    Color Spaces for Skin Segmentation

Color is not an intrinsic property of objects, but a perception of another property which is an object's interaction with light photons. An object with red color emits only red wavelengths with different quantities, whether it is self-emitting or reflecting light photons. The perception of the emitted photons from objects is what is defined as color. The receptors in the eye send signals to the brain that are respective to the received wavelengths (chrominance) and their quantities (intensity of color).

A good analogy would be the perception of an object mass by its weight. An object with a mass of 1 Kilogram (real property) weighing 10 Newton (perception) when situated in the earth's gravitational field $G$, weighs less in the moon's gravitational field instead. Again, this is analogous to exposing an object to different lighting conditions which are perceived as having different colors. Consequently, careful consideration should be accounted for when dealing with color. As various color models were invented to quantize color with numerical values, each of them has different ways of describing colors. The following subsections are dedicated to the color spaces used in our paper.

### 2.3.1. RGB

In RGB, color is defined by three primary colors (three values) Red, Green, and Blue. Each combination of these values gives a different color. The RGB model might be the simplest to represent color, thus it is suitable for technical applications, however, it has a major drawback that its *R*, *G*, and *B* values are highly correlated. They collectively carry the intensity (luminance) and color (chrominance) information. This behavior is not perceptual hence not preferred in image classification applications.

### 2.3.2. YCbCr

YCbCr is one of the models that separates luminance and chrominance information. The *Y* component carries the luminance information, whereas the *Cb* and *Cr* together carry the chrominance information. The conversion from RGB to YCbCr is done by Equations 5, 6, and 7 described below.

$$Y = R\frac{77}{256} + G\frac{150}{256} + B\frac{29}{256} \tag{5}$$

$$Cb = B - Y \tag{6}$$

$$Cr = R - Y \tag{7}$$

Many skin segmentation articles used this color space, due to the separation between color and intensity information as well as its simple transformation from RGB.

## 3.    Experiments

The goal of this study is to compare the performance of five major SL models for pixel-based skin segmentation, evaluate the effect of using different color spaces on the performance of each model and assess the effect of duplicated records on the results. To achieve this, RGB and YCbCr color spaces were adopted and different thresholding and ranking evaluation metrics were used to settle the comparison.

### 3.1.   Dataset Specifications

The dataset is taken from the UCI machine learning repository. Skin segmentation dataset [21] has a sample size of 245057 out of which 50859 (21%) are skin samples, and 194198 (79%) are non-skin samples. Each sample comprises RGB values of a pixel taken randomly from a human face image associated with a binary label referring to either skin (1) or non-skin (0). Face images of various age groups (young, middle, and old), race groups (white, black, and Asian), and genders obtained from FERET and PAL databases were involved in forming the dataset. The dataset includes duplicated records with 51444 unique ones (28% skin and 72% non-skin). Only 11 distinct RGB tuples out of 51444 refer to both skin and non-skin at the same time.

## 3.2.  Data Preprocessing

Having a small region of overlap between skin and non-skin implies the dismissal of redone records outwardly influencing the classification performance. First, the RGB values were turned into YCbCr, then both were visualized for two cases, with and without duplicates. Figure 4 shows the consequence of converting RGB values into YCbCr for both skin and non-skin pixels, on the left with duplicates, and on the right without duplicates. We can see that for *Cb*, and *Cr* values are focused on narrower bands than the other attributes. Additionally, removing duplicated records increases the data spread over a wider range which might be significant for some ML algorithms.
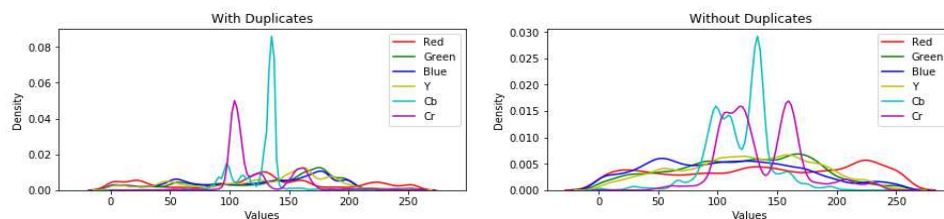


**Figure 4**: Density Plots of RGB And YCbCr Values of Skin and Non-skin Pixels

From Figure 5 and Figure 6, we can perceive that in YCbCr skin and non-skin values are less overlapping concerning *Cb* and *Cr* values that hold the chrominance feature (color) while in *R*, *G*, *B*, and *Y* there is no clear separation. However, considering only *Cb* and *Cr*, the overlapping happens at 2430 distinct tuples (instead of 11). So, disregarding the *Y* component will certainly increase the prediction error. This proves the fact that luminance (intensity) is also an important feature of skin and should not be disregarded if optimal performance is required. To confirm this, the experiment was repeated on different combinations of features including RGB, YCbCr, and CbCr color spaces. Also, the effect of eliminating duplicates was examined by experimenting on classifiers' performances with and without duplicates.
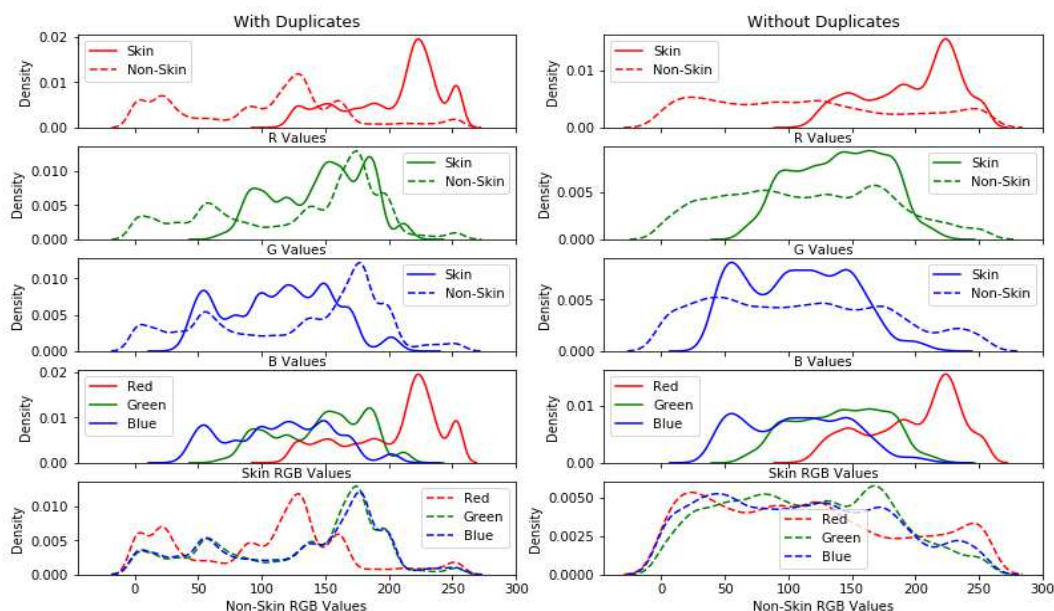


**Figure 5**: Density Plots of RGB Values of Skin and Non-skin Pixels
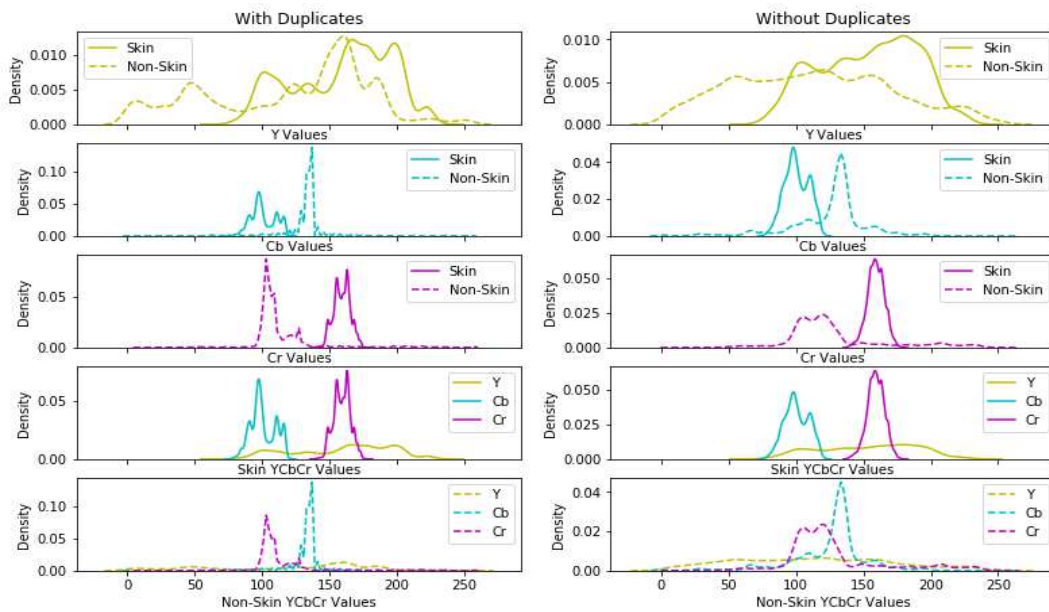
**Figure 6**: Density Plots of YCbCr Values of Skin and Non-skin Pixels

Figure 7 and Figure 8 show pair-plots of six attributes *R*, *G*, *B, Y*, *Cb*, and *Cr* with and without duplicated samples, respectively. The upper right triangle exhibits scatter plots of the actual data, while the lower triangle has 2D probability density plots. Again, the separation of *Cb* and *Cr* is more obvious in these figures.
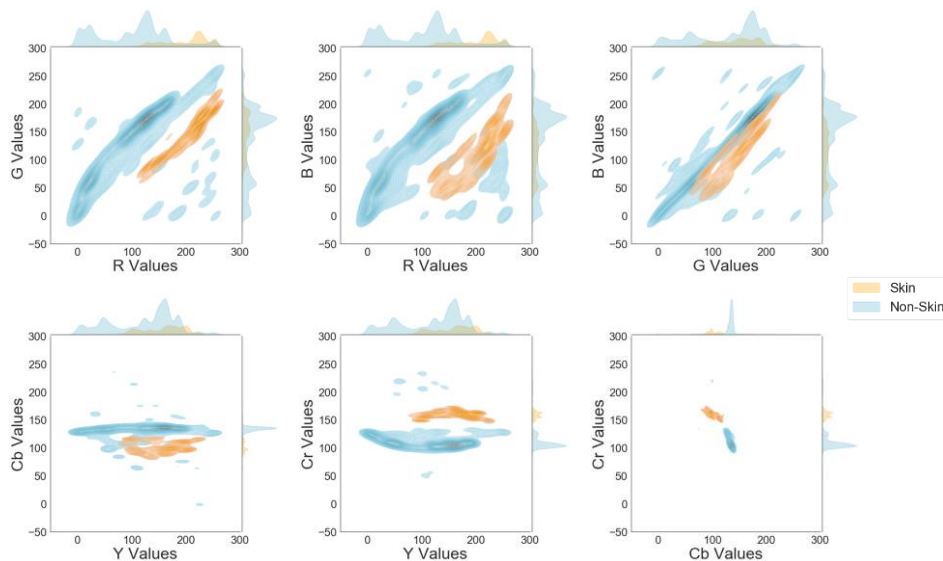


**Figure 7**: Pair-plots of RGB and YCbCr Values of Skin (in orange) and Non-skin (in green) Pixels Including Duplicates
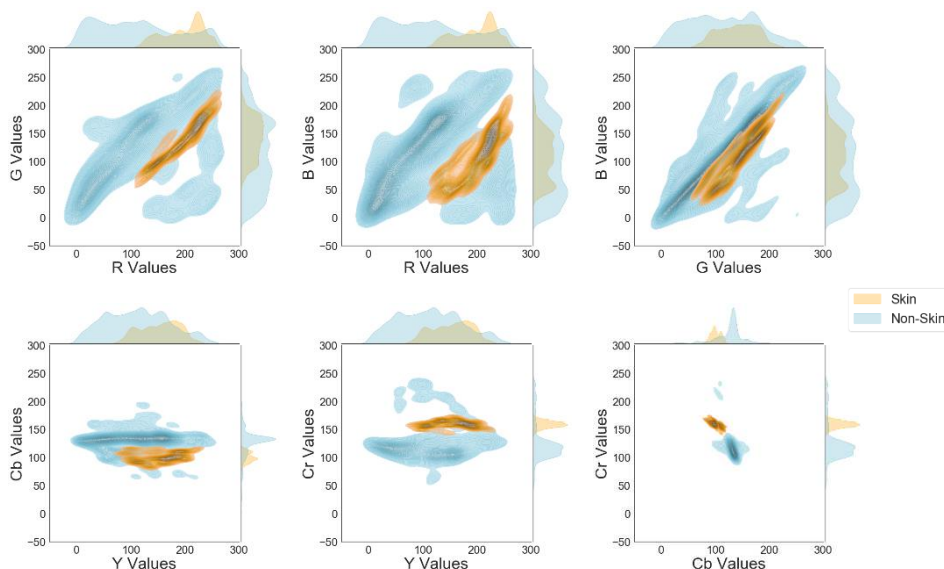
**Figure 8**: Pair-plots of RGB and YCbCr Values of Skin (in orange) and Non-skin (in green) Pixels Without Including Duplicates

## 3.3. Hardware and Runtime Environment

The experiments were conducted using HP Pavilion 14-ce1003ne Laptop under the hardware and runtime environment (RTE) described in Table 1.

| Specification | Description |
|---|---|
| Processor | Intel® Core™ i5-8265U (1.6 GHz base frequency, up to 3.9 GHz with Intel® Turbo Boost Technology, 6 MB cache, 4 cores) |
| Memory | 16 GB DDR4-2400 SDRAM (1 x 16 GB) |
| Storage | Crucial MX500 1TB 3D NAND SATA 2.5-inch 7mm SSD |
| Video Graphics | NVIDIA® GeForce® MX150 (2 GB GDDR5 dedicated) |
| Operating System | Windows 10 Home 64 |
| RTE | Spyder IDE (Anaconda3) - Python 3.7.6 |

**Table 1**: Hardware and Software Environment Specifications

## 3.4. ML Training Configuration

For our comparison, we used known SL methods (SVM, KNN, NB, DT, and LR). The implementation of these SL methods is publicly available and can be directly imported from the *sklearn* library [22]. The details and parameter setting of each classifier is given in Table 2.

| Classifier | Algorithm used | Parameters | |
|---|---|---|---|
| **SVM** | sklearn.svm.LinearSVC | loss=squared_hinge | $C$=1 |
| **KNN** | sklearn.neighbors.KNeighborsClassifier | n_neighbors=5 | $p$=2 |
| **NB** | sklearn.naive_bayes.GaussianNB | var_smoothing=1e-9 | |
| **DT** | sklearn.tree.DecisonTreeClassifier | criterion=gini | |
| **LR** | sklearn.linear_model.LogisticRegression | penalty=l2 | |

**Table 2**: Parameters Settings of The Classifiers Used for The Experiments

For SVM, and more specifically Linear SVC (Support Vector Classifier), $C$ is used for regularization, which describes a squared *l2* penalty, while the squared hinge is used as a loss function. In KNN, $K$=5 with equal weights for neighbors and the Euclidean norm to measure the distance ($p$=2). For DT, the Gini impurity criterion was selected to measure the quality of a split. To train and evaluate SL models, the K-fold cross-validation technique is used. It is commonly applied when the sample size of the dataset is small, and to give more realistic results overall. It involves randomly splitting the dataset into $K$ groups ($K$=5 in our case), keeping the same data distribution among classes inside each group. Training and evaluating the model happens $K$ times by taking each group as testing data at a time while preserving all the others as training data. Eventually, scores obtained from the $K$ trials are used to evaluate the model skill.

# 4.    Experimental Results

## 4.1.    Evaluation Metrics

After training the models, evaluation metrics are employed to compare SL methods. As our dataset is imbalanced, the use of common metrics can lead to a sub-optimal classification and might produce misleading conclusions, since these measures are insensitive to skewed domains [23]. Due to this fact, various metrics were selected to ensure a more realistic comparison. The confusion matrix is first presented as many other metrics can be extracted from it.

| | **Predicted as Positive** | **Predicted as Negative** |
|---|---|---|
| **Actually Positive** | True Positives (TP) | False Negatives (FN) |
| **Actually Negative** | False Positives (FP) | True Negatives (TN) |

**Table 3**: Confusion Matrix

For a binary classification problem, the confusion matrix has 4 entries (as described in Table 3). The diagonal holds the correct predictions, namely true positives (TP) and true negatives (TN), whereas false positives (FP) and false negatives (FN) are off the diagonal, they refer to the wrong predictions made by a classifier. From the confusion matrix, we can extract the classification accuracy, precision, recall, and F1-score which are illustrated in Table 4.

| Metric | Definition |
|---|---|
| Accuracy (ACC) | $(TP + TN) / (TP + FP + FN + TN)$ |
| Precision (*P*) | $TP / (TP + FP)$ |
| Recall (*R*) | $TP / (TP + FN)$ |
| F1-Score (F1) | $P \times R / (P + R)$ |

**Table 4**: Binary classification metrics extracted from the confusion matrix

The metrics mentioned so far are known as *threshold* metrics; they are concerned about quantifying the error in prediction. However, the ones discussed now are relevant to class separation; they are called *ranking* metrics. ROC-AUC (Receiver Operating Characteristic – Area Under Curve) is the most used metric in this regard, it is defined as the area under the curve having False Positive Rate (FPR) on the x-axis, and True Positive Rate (TPR, also known as recall) on the y-axis. TPR and FPR are defined by Equations 8 and 9, respectively.

$$FPR = \frac{FP}{FP + TN} \tag{8}$$

$$TPR = \frac{TP}{TP + FN} \tag{9}$$

The ROC curve is generated by diversifying the discrimination threshold of the model, calculating TPR and FPR for each case, and connecting the resulting points. The closer the model to the upper-left corner, the larger ROC-AUC, and the better classification will be. ROC-AUC can give confident results, in general. Though, for a severely imbalanced dataset it might be optimistic, especially if the minority class records are few. PR-AUC (Precision-Recall – Area Under Curve) focuses on the minority class, hence gives a better evaluation in our case. Like ROC-AUC, the PR curve is formed by connecting the points having precision on the y-axis versus recall on the x-axis for different thresholds. The perfect classifier resides at the upper-right corner (Figure 9).
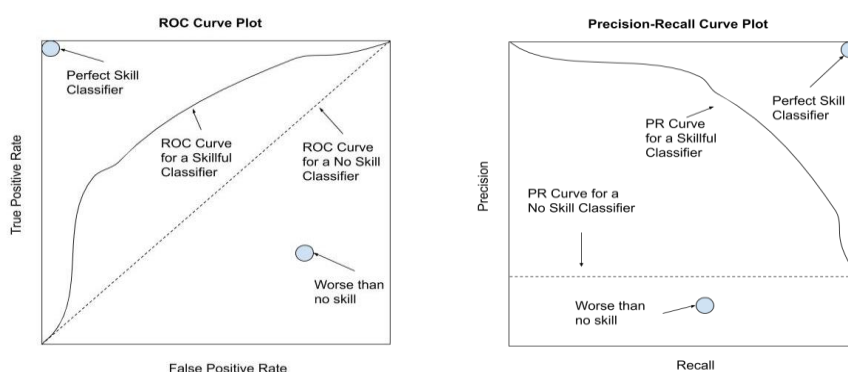


**Figure 9**: ROC and PR curves [24]

## 4.2. Results

Experimental results on skin segmentation dataset revealed that in most of the cases and despite the parameters and the metrics used, KNN outperformed other SL methods.

Table 5 shows the confusion matrix entries of the results for all the experiments performed. From these parameters, two threshold metrics (Accuracy and F1-score) were derived (and, if needed, others can be calculated for further comparison). Two ranking metrics (ROC-AUC and PR-AUC) were generated by diversifying the discrimination threshold. These four metrics are presented in Table 6 and depicted graphically in Figure 10. The best values (higher true predictions marked with "+" and lower false predictions marked with "-" for the confusion matrix entries) of each metric in both tables (Table 5 and Table 6) are highlighted in bold for the six cases of different color spaces and with/without duplicates.

The confusion matrix entries in Table 5 suggest that KNN and DT are the best in classifying skin and non-skin pixels. However, a closer look tells that KNN focuses on the minority class (i.e., TP and FN are actual skin pixels) whereas DT on the majority (i.e., TN and FP are actual non-skin pixels). In other words, KNN is more useful in identifying skin pixels while DT is better in detecting non-skin pixels. This is precisely the definition of the recall metric for each class. Therefore, Table 6 reveals that DT only has one occasion where it outperforms the other SL methods with an F1-score of 95.94% in the case of CbCr color space with duplicates. Furthermore, KNN still has the best overall F1-score of 98.49% concerning the case of YCbCr with duplicates. We conclude that the direct usage of confusion matrix entries is misleading in finding the best classifier.

| Model | With duplicates | | | | Without duplicates | | | | Color space |
|---|---|---|---|---|---|---|---|---|---|
| | TP | FP | TN | FN | TP | FP | TN | FN | |
| SVC | 16292 | 7422 | 186776 | 34567 | 751 | 1623 | 35167 | 13903 | **RGB** |
| KNN | **49749⁺** | 908 | 193290 | **1110⁻** | **14362⁺** | 721 | 36069 | **292⁻** | |
| NB | 37115 | 5202 | 188996 | 13744 | 10789 | 3608 | 33182 | 3865 | |
| DT | 45864 | **901⁻** | **193297⁺** | 4995 | 13338 | **467⁻** | **36323⁺** | 1316 | |
| LR | 40236 | 11585 | 182613 | 10623 | 8720 | 5333 | 31457 | 5934 | |
| SVC | 31163 | 11555 | 182643 | 19696 | 8055 | 6370 | 30420 | 6599 | **YCbCr** |
| KNN | **49999⁺** | 659 | 193539 | **860⁻** | **14366⁺** | 537 | 36253 | **288⁻** | |
| NB | 46163 | 1669 | 192529 | 4696 | 13408 | 321 | 36469 | 1246 | |
| DT | 46779 | **220⁻** | **193978⁺** | 4080 | 13673 | **188⁻** | **36602⁺** | 981 | |
| LR | 40199 | 11470 | 182728 | 10660 | 8707 | 5342 | 31448 | 5947 | |
| SVC | 30362 | 19114 | 175084 | 20497 | 2931 | 7310 | 29480 | 11723 | **CbCr** |
| KNN | **47519⁺** | 355 | 193843 | **3340⁻** | **14010⁺** | 283 | 36507 | **644⁻** | |
| NB | 46172 | 2194 | 192004 | 4687 | 13275 | 327 | 36463 | 1379 | |
| DT | 47334 | **296⁻** | **193902⁺** | 3525 | 13341 | **239⁻** | **36551⁺** | 1313 | |
| LR | 37600 | 12618 | 181580 | 13259 | 4959 | 5738 | 31052 | 9695 | |

**Table 5:** Confusion Matrix Entries for Various Cases of Color Space and Duplicate Inclusion

From Table 6, we observe that the two SL models that share the best values for all the metrics are KNN and NB (except for one occasion for DT). Hence, we will use them first to evaluate the effect of color spaces and duplicates on the skin segmentation problem. For KNN, converting from RGB to YCbCr enhances the results for all the metrics, but going from YCbCr to CbCr makes them all worse. For example, moving from RGB to YCbCr in case of including duplicates, changes the accuracy from 99.18% to 99.38%, F1-score from 97.98% to 98.49%, ROC-AUC from 99.18% to 99.40%, and PR-AUC from 98.03% to 98.39%. However, moving from YCbCr to CbCr

color space changes the values back down to 98.49%, 95.85%, 97.37%, and 95.46%, respectively, which are even worse than the case of RGB color space. This suggests that intensity (*Y*) is an important feature for skin segmentation and that chrominance information (*Cb* and *Cr*) is not enough to discriminate skin. Surprisingly enough though, NB shows the same behavior when moving from RGB to YCbCr but neglecting the *Y* feature does not affect the ranking metrics, while slightly degrading performance in terms of threshold metrics. From this, we can conclude that intensity importance is relevant to the algorithm used. Nonetheless, we can say that generally YCbCr is the best color space among the three for skin segmentation.

Considering only the YCbCr now, the dismissal of duplicate records gives worse performance for KNN despite the metric that we apply. For NB, there is a slight change in values up and down for both metric types. Hence, again we can say that the importance of information held by duplicate records is relevant to the algorithm used.

Now to compare SL algorithms, by considering only the threshold metrics, KNN dominates in five cases out of six. Consequently, this leads to considering KNN as the best classifier regarding the prediction error with a maximum accuracy of 99.38% and F1-score of 98.49% both in YCbCr color space with duplicates. If ranking metrics are considered however, NB gives the best results in four cases out of six (all in YCbCr and CbCr) and maximum overall values of 99.75% and 98.51% for ROC-AUC and PR-AUC, respectively. This concludes that NB could separate class instances better than KNN did when YCbCr and CbCr color spaces were adopted. However, if we consider the case of YCbCr including duplicates, KNN gives 99.40% and 98.39% for ROC-AUC and PR-AUC, respectively, which are very close to the overall maximum values of NB. As KNN is continually leading in terms of threshold metrics, we can assume that KNN is better than NB for skin segmentation classification, and the best among all SL models considered in our paper.

| Model | With duplicates | | | | Without duplicates | | | | Color space |
|---|---|---|---|---|---|---|---|---|---|
| | ACC | F1 | ROC-AUC | PR-AUC | ACC | F1 | ROC-AUC | PR-AUC | |
| **SVC** | 81.95 | 45.91 | 93.34 | 69.07 | 65.14 | 21.59 | 81.84 | 55.07 | **RGB** |
| **KNN** | **99.18** | **97.98** | **99.18** | **98.03** | **98.03** | **96.59** | **98.93** | **96.64** | |
| **NB** | 92.27 | 77.49 | 93.61 | 84.45 | 85.47 | 73.27 | 93.13 | 85.9 | |
| **DT** | 97.59 | 93.19 | 94.85 | 90.54 | 96.56 | 93.57 | 94.96 | 90.6 | |
| **LR** | 90.94 | 77.63 | 94.59 | 70.51 | 78.1 | 59.28 | 85.79 | 63.7 | |
| **SVC** | 92.03 | 81.95 | 94.26 | 68.96 | 71.63 | 61.91 | 83.15 | 58.06 | **YCbCr** |
| **KNN** | **99.38** | **98.49** | 99.4 | 98.39 | **98.4** | **97.2** | 98.97 | 96.81 | |
| **NB** | 97.4 | 92.71 | **99.75** | **98.51** | 96.95 | 94.24 | **99.6** | **98.57** | |
| **DT** | 98.17 | 95.07 | 95.77 | 92.97 | 97.76 | 95.89 | 96.51 | 94.13 | |
| **LR** | 90.97 | 77.66 | 94.58 | 70.44 | 78.06 | 59.15 | 85.79 | 63.68 | |
| **SVC** | 86.67 | 72.45 | 94.48 | 67.18 | 67.17 | 39.98 | 83.72 | 59.14 | **CbCr** |
| **KNN** | **98.49** | **95.85** | 97.37 | 95.46 | **98.2** | **96.78** | 98.46 | 96.71 | |
| **NB** | 97.19 | 92.21 | **99.75** | **98.55** | 96.68 | 93.8 | **99.62** | **98.47** | |
| **DT** | 98.44 | 95.94 | 96.7 | 94.4 | 96.98 | 94.46 | 95.69 | 92.79 | |
| **LR** | 89.44 | 73.88 | 94.05 | 67.89 | 70 | 33.78 | 84.74 | 62.02 | |

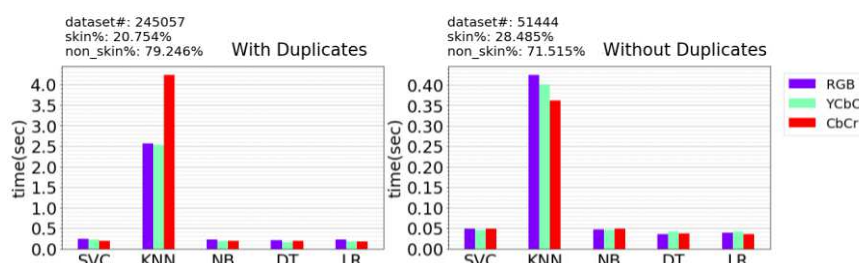**Table 6:** Summary of Experimental Results for Skin Segmentation Dataset
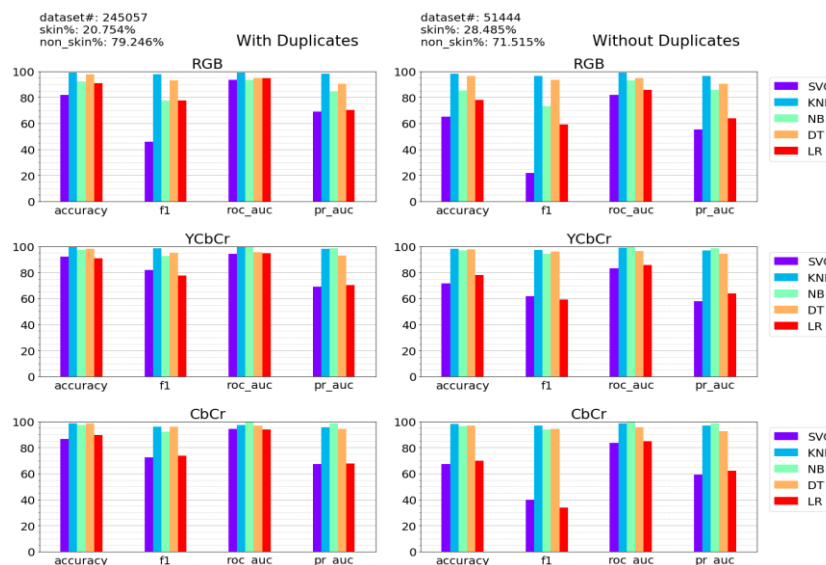
**Figure 10**: Comparative Graphical Representation of The Achieved Results by SL Methods for Skin Segmentation Dataset Classification

Nonetheless, if execution time is crucial, which is the case in real-time applications, then opting for NB is more beneficial. Indeed, based on Table 7 and Figure 11 which indicate the execution time for each classifier (best results are marked with bold), we can quickly discern that KNN takes much more time than any other SL method. The reason of this phenom is clear, KNN algorithm measures the distance between a new instance and all existing instances, stores the indexes and the distances in a collection, sorts the collection in ascending order, selects the class label of the *K* first records from the collection, and finally applies the mod of the *K* class labels as a label for the new instance. Those steps are repeated for each instance belonging to the test set, which makes the execution time of KNN very long as opposed to other SL methods.

| With duplicates | | | | | Without duplicates | | | | | Color space |
|---|---|---|---|---|---|---|---|---|---|---|
| SVC | KNN | NB | DT | LR | SVC | KNN | NB | DT | LR | |
| 0.239 | 2.562 | 0.223 | **0.211** | 0.218 | 0.048 | 0.424 | 0.047 | **0.036** | 0.039 | **RGB** |
| 0.226 | 2.534 | 0.188 | **0.167** | 0.179 | 0.045 | 0.401 | 0.045 | 0.042 | **0.041** | **YCbCr** |
| 0.197 | 4.235 | 0.188 | 0.196 | **0.178** | 0.048 | 0.361 | 0.048 | 0.037 | **0.035** | **CbCr** |

**Table 7:** Summary of Experimental Results in Terms of Execution Time (sec)



**Figure 11**: Comparative Graphical Representation of The Achieved Results by SL Methods for Skin Segmentation Dataset in Terms of Execution Time

## 5.    Conclusion

In this study, we addressed the skin segmentation problem based on pixel color using SL methods. We aimed to find the best color space among RGB and YCbCr for this purpose, we investigated the effect of the intensity ($Y$) on skin segmentation classification, we also evaluated the effect of duplicate records dismissal on the classification results, and eventually, we found the best SL model for skin segmentation classification considering all the aspects mentioned above.

In all the cases, YCbCr was perceived to be better than RGB. The intensity ($Y$) importance was found to be relevant to the algorithm used, for instance, KNN performed better considering the intensity ($Y$), but NB was almost not influenced by it. Duplicates' influence was also found to be relevant to the used algorithm. KNN performed better with duplicates, and NB almost gave even results. The best SL model that outperformed all the other SL models in almost all the cases considered is KNN. Despite this, evaluation metrics were found crucial for finding the superior SL model. In the case of threshold metrics, KNN outperformed all the other classifiers, still, NB achieved commending results while considering the ranking metrics. As a result, metrics should be chosen carefully for each specific application. Execution time is also an important factor in the decision of the best model, the KNN algorithm was the worst in this regard.

For future works, we suggest focusing on a specific skin segmentation application and trying to find the best evaluation metric that suits the application in concern then making the comparison again. Adopting other SL methods such as artificial neural networks (ANN), convolutional neural networks (CNN), or deep neural networks (DNN) will be examined. Also, the inclusion of other color spaces that separate intensity and color information is of great interest. Finally, experimenting on a different dataset will guarantee more robust results. For example, the ECU dataset [25] which consists of 4,000 color images with ground-truth prepared manually for skin segmentation and face detection. It is the largest dataset available with 209 million skin pixels and 902 million non-skin pixels.

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