Technological Solution Development During the COVID-19 Pandemic: a Case Study in an IoT Lab

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***Abstract*—Major crisis in human history impose new challenges to all people affected by it. These great challenges usually represent a great opportunity for technological development, since technological solutions are a significant part of the effort to overcome crisis. The COVID-19 pandemic is no exception to this historical trend. We present in this work the development of a technological solution for one challenge imposed by the corona virus outbreak: disinfection of enclosed spaces. Hence, the objectives of this work were: 1 - To present some of the technical choices made to develop the sanitization solution using UVC light; 2 - To present a methodological framework to adapt R&D work to the needs of social/physical distance; 3 - To assess the productivity of the members of the UIoT laboratory during this remote work period. The solution development was carried out by a multidisciplinary team and, in order to evaluate the proposed methodology, a questionnaire was used to assess the team member's perception of productivity. Its results show an overall quality increase, and an individual quantity increase regarding the project's outputs. We concluded that the projects' results were better than what was expected at the beginning of the year.**

I. Introduction

Major crisis in human history, caused by wars, extreme weather or plagues, impose new challenges to all people affected by it. This challenges may be new in its scales (e.g. a local drought that cause mass famine) or completely new (e.g. the first encounter between the Aztecs and the Spanish). Regardless of its novelty, these great challenges usually represent a great opportunity for technological development, since technological solutions are a significant part of the solutions created during a period of crisis [1]. The COVID-19 pandemic is no exception to this historical trend. The outbreak caused by Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) has impacted all aspects of human life in a way not seen since World War Two [2].

There are many particular challenges presented by the this pandemic that may benefit from technological solutions, such as low-cost mechanical ventilators and contact tracing Apps [3], [4]. Each one of those technologies tackle a specific sub-problem, patient treatment and virus-spread prevention, respectively. However, an unique challenge imposed by the COVID-19 pandemic is the need to social/physical distance, in order to reduce the spread of the coronavirus. This new daily-life requirement directly impacts the technology development process, specially hardware depended technologies. Therefore, using the previous example, in order to develop a low-cost mechanical ventilator, a Research and Development (R&D) team need to adapt its work practices and its technology development processes to comply with social/physical distancing rules [4].

This double-challenge, developing technological solutions while social/physical distancing, was faced by our team at the Universal Internet of Things (UIoT) laboratory, of the University of Brasília (UnB), in Brazil. In the middle of March, all in-person activities were suspended, what effectively halted all hardware related projects. At the start of June, some pure-software solutions were being developed, but no hardware related group work was being carried out. Thus, we decided to start a hardware-related IoT project to tackle a issue brought into the spot-light by the pandemic: disinfection of enclosed spaces.

The problem of sterilizing and cleaning enclosed spaces is not a new one. However, it was elevated to a new scale with the SARS-CoV-2 outbreak, like other similar challenges. Therefore, the biggest challenge is to adapt the sterilization and cleaning technology to new uses and make it affordable to the wider public. A relative low-cost and scalable technology, ultraviolet type C light (UVC) has been used for more than 100 years [5] in different working conditions. Its well-know behavior and previous uses in hospitals and laboratories [6], [7] makes it a natural choice as a solution principle from which a more affordable and accessible solution can be developed.

Therefore, this work aims to present the development of an IoT disinfection solution for enclosed spaces and the changes in work practices and development processes adopted by the UIoT team in charge of this R&D project. The objectives that follow this main aim are: 1 - To present some of the technical choices made to develop the IoT sanitization solution using UVC light; 2 - To present a methodological framework to adapt R&D work to the needs of social/physical distance; 3 - To assess the productivity of the members of the UIoT during this remote work period.

The remaining of this work is organized as follows: section II presents some relevant works found in the related literature. Section III shows the solution's development process, describing what was done and how the work was adapted. A performance assessment of the UIoT team is presented in section IV, on which a questionnaire was used to obtain the people's productivity perspectives. Finally, section V contains our conclusions and some future work suggestions.

II. Related Works

The work of Cui [8] presents a design approach for a rapid test kit to detect SARS-CoV-2. It has many similarities with this work, since both works were motivated by the current pandemic, and strive to develop solutions for it. Also, common practices can be seen at the methodological level, such as the need to select solution principles and technologies in order to make accelerate the development process.

Concerning how the project was organized and the methods used, the case-study shown by Vogel [9] demonstrate how Project-Based Learning (PBL), Scrum and rapid prototyping can have a positive influence at student research projects in the IoT field. The case-study results reported knowledge, teamwork and adaptability increases when using Scrum in IoT prototype development. The research environment (university),the use of PBL and Scrum were all considered common points between our works. The use of such methodologies was needed according to the pandemic context to rapid prototype and quickly develop a solution.

Regarding the productivity aspect, a parallel can be made with the analysis conducted by Melo [10], in which the perception of productivity in agile teams and the factors that have an impact on it are collected and analyzed. In order to support the work, nine dimensions are used to define the productivity of a knowledge worker, which can be seen below.

1) Quantity
2) Cost
3) Timeliness
4) Autonomy
5) Efficiency
6) Quality
7) Effectiveness
8) Project success
9) Customer satisfaction

Although the context is quite different to the one we are currently evaluating in this work, since it evaluated two large private companies using collocated workers, there are several similarities such as the need to first understand what the group perceives as productivity. Also, the structure of the data collection method used, the dimensions defined above and the findings were the main reference to elaborate the evaluation form used to acquire data in this work.

Another important observation regarding the analysis of productivity was made by Petersen [11], who recommends that new productivity factors need to be considered with the change in developing software, and old factors have to be re-evaluated when there is a new context, as the one we are in due to the Covid-19 outbreak. This consideration is also applicable to hardware development, as in many cases it goes alongside with software development.

About the academic development of IoT solutions at the laboratory, it is possible to see a fog computing solution that monitors and control environments [12] and a way to track intruders in IoT networks at [13]. Both solutions are a background of how the group was used to work and this work shows the way the group managed to adapt to the pandemic challenges.

III. Solution Development

Accordingly to the pandemic scenario, the team had to adapt the Research and Development workflow in every step of the development of the technological solution. Using the traditional Product Development Process (PDP) as a starting point, in special the model used by Amaral et al.[14], an adaptation to the current scenario was proposed. That was needed for a couple of reasons: to better adapt to the pandemic challenges and to adjust the PDP to the context of a research laboratory, since it was originally proposed for market-driven companies with a pre-existing product portfolio. Fig. 1 shows the flowchart of the proposed model.

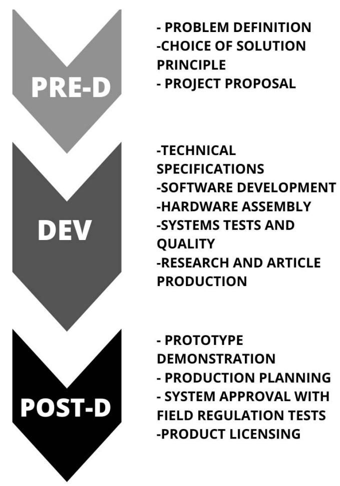

Fig. 1. Fast Solution Development Model

The proposed model is target to laboratories and groups of autonomous developers. Our approach to present the model is to explain its theoretical background followed by examples on how we applied it on the development of the IoT sanitization solution. The first part of the model is the pre-development, which consists in defining the problem, choosing the solution principle that consist the basis of the technological solution and make a project proposal to be validated by all stakeholders.

In the evaluated scenario, the problem had a very clear scope: sterilizing and cleaning enclosed spaces and surfaces. To determine the technological solution and the solution principal, three aspects were taken in consideration: the team skills, the technological accessibility and the relevance of the solution to solve the problem. About the skills, since the UIoT team can be considered a multidisciplinary one, focused at internet of things technologies, we opted for a embedded solution. The contributions of multidisciplinarity while developing a fast IoT solution, with a geographically dispersed team can be seen at [15]. Regarding the technological accessibility, we choosed the UVC lights for decontamination of surfaces and small environments, as it is highly reliable [5] and considerably accessible in the market. About the relevance of the work, we noted a lack of similar solutions in the national market, even with the consolidated use of the UVC technology for other uses. That makes the proposed solution relevant for the laboratory's context.

To make the project proposal document, the last step of the pre-development, the solution requirements were listed from the identified needs and premises. The aspects taken in consideration were physical, legal, risk, operational and the contribution for the problem in question. After the requirements were listed, a list of functions the solution should perform was made according to the use cases. Having the functions, the group could make a morphological matrix, a key tool to list in a more effective way the possible solution principles for every function, as shown in [16]. In the traditional workflow this would be typically done with a white board and a presidential meeting, but to adapt, the group made a virtual meeting in order to gather all the suggestions. At the end, the best combination of solution principles was decided and a draft of the solution was made to be prototyped later.

After the project proposal is accepted by all stakeholders, the development phase, the Fast Solution Development Model begins. At this point, the Scrum-like methodologies are recommended. As stated by Lei [17], agile methodologies such as Scrum are more effective than traditional project management ones, by providing opportunities to adapt the project proposal as new needs and limitations appear. In our case, the use of Scrum provided the team with flexibility to transition to remote work and to adapt to develop most of the work through virtual meetings. For the solution development, the team was divided according to their skills and assigned to different task groups: software development, hardware assembly, systems test and quality verification, as well as research academic papers writing.

Some of the usual activities during this phase includes developing and simulating the electrical circuit, creating 3D models, diagrams and documenting all the specifications that the solution contains. We counted on circuit simulation software in order to improve the circuit and reduce the risk of failure.

Also, for projects contains software, this phase includes all the software development necessary for the solution. Some activities include: implementation of algorithms, hardware programming and module's communication. After been designed the hardware need to be assemble. This process requires the definition of a bill of materials beforehand, and subsequent tests of all components, in order to finally assemble the circuit. As previously mentioned, our hardware team was heavily affected by the changes duel to social/physical distancing. Than, there was the need to treat the laboratory as an asset, registering and managing its use, so that team members had no physical contact with each other to reduce the risk of contamination.

Another crucial part at the development process is the system tests, which happens in different stages of the process. The performance of the solution should be analyzed and feedback given to all other teams, according to the needs of the project. Simultaneously, the research team work looking for new trends in the related literature and suggest better practices. Our team was able to gather information from new sources as new pandemic related articles were published. This information was important to keep our work updated to the latest data about Covid-19 and the technologies used to contain its spread.

The final stage of the Fast Solution Development Model consists of making a prototype demonstration, planning the production phase, getting system approval with field regulation tests and getting the product licensed. In other words, the goal of this stage is to increase the Technology Readiness Level (TRL)of the solution. By increasing the TRL, scale used to classify the technological maturity of products and systems [18], the confidence on the technology increases to the point it becomes market-ready.

IV. Performance Assessment

The understanding of productivity can vary depending on the type of work and the context one is inserted in. There are several concepts related to this, as specified by Melo in [10], such as efficiency, quality, effectiveness, cost, and experience. Another important definition is that both software and hardware development, especially in the research field, is mental work involving knowledge creation and knowledge use in a dominant part of the work, as defined in [19]. Also, as Drucker [20] states, the productivity of a knowledge worker is strongly related to ones degree of autonomy, responsibility and continuous life-long learning experience.

To evaluate the team's perception of productivity, an online questionnaire was sent to the whole research group, including other researchers that are not directly involved with this specific project. Those other researchers where used as a control group in the analysis, since in the other projects they usually apply a more traditional approach to software and hardware development. Also, the three development groups (hardware, software and security) were considered when assessing the productivity perception, since the participants tend to work mainly with other researchers within the same development group. Finally, the questionnaire was anonymous, so that the interviewees would feel more comfortable responding. The full questionnaire, translated to English, can be seen at https://bit.ly/32QWrCG.

The main objectives of the evaluation questionnaire were to map the understanding of productivity among our team at the UIoT and the perception of the researchers regarding their own productivity and the productivity of the work group they were inserted in. To map the understanding of productivity is an important step in the analysis because, as Melo [10] stated, it can vary from person to person and that variation can have a direct impact on the results. Since this was a first trial of the assessment, and the beginning of a continuous improvement work, it was also important to have the teams understanding of productivity so that it can be used in the future to measure the groups perception of productivity more accurately.

Beginning with the definition of productivity, the interviewees could indicate which of the dimensions show in the Table I they associated with productivity. The results can be seen in the graph shown in Fig. 2, in which one can see that efficiency was indicated by most of the interviewees (86%) and the quantity was the second, indicated by 67% of the interviewees. One of the participants even wrote the following statement: ”A process is more productive when it delivers a task faster or delivers more tasks in the same period of time. That is, considering that the deliverable has equal quality [in both cases]. If the quality varies, then the more productive would be the one that delivers more tasks with less need for rework or the one that is faster at a task 100% functional.”

Another interesting finding is that only 10% of the participants considered the cost and multitasking dimensions related with productivity. The cost aspect can be explained by analyzing the profile of the group, since most of them do not deal with the financial aspect of the development it, the cost associated with the research done can be less tangible than other dimensions.

TABLE I
DIMENSIONS OF PRODUCTIVITY

Dimension	Definition
Cost	Cost by specific number of activities done
Effectiveness	To perform the right activities
Efficiency	To perform activities correctly
Multitasking	Number of activities performed in parallel
Quality	Quality of activities done in a specific time period
Quantity	Number of activities done in a specific time period
Timeliness	Activities delivered on time
Value	Final value delivered in a specific time period

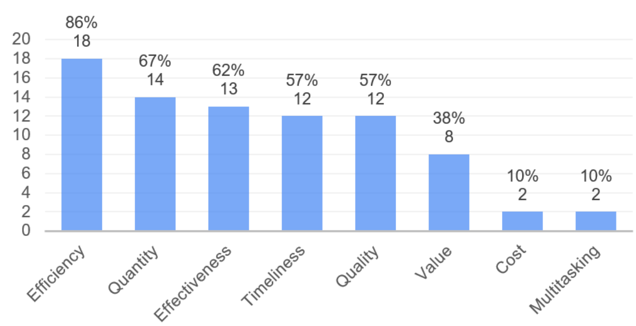

Fig. 2. Dimensions associated with productivity

The next analysis is about the perception of productivity achieved during social/physical distancing time (quarantine). The graphs in Fig. 3 and 4 show the results of individual and team perception of productivity, respectively. Considering the results shown, one can see that most participants (57%) have a positive perception of their own productivity, being that 38% found that their productivity increased a lot and 19% found that it increased a little. However, the results for the team's productivity was not the same. Only 33% of the interviewees have a positive perception of the team's productivity. In fact, 43% have a negative perception, where 38% found that the team's productivity decreased a little and 5% found it decreased a lot. This difference in perception was expected, although it renders the results inconclusive at first.

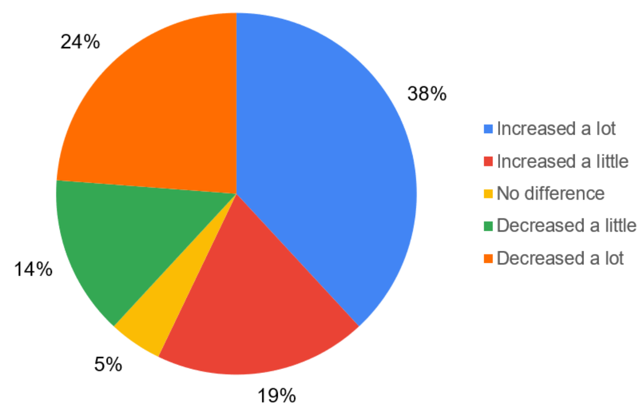

Fig. 3. Perception of individual productivity

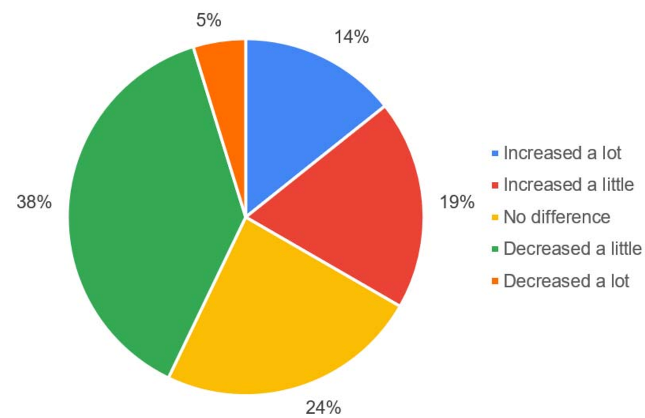

Fig. 4. Perception of team's productivity

The last aspect analyzed is which productivity dimensions the participants found any improvement or worsening, both in their individual productivity and their perception of the team's. For this analysis specifically the dimensions used where only quantity, quality and velocity, since the others are less tangible and their evaluation could be compromised because of that. The results of the perception of improvement and worsening in the work done are shown in Fig. 5 and 6, respectively.

The most important finding with that analysis was that 48% of the participants saw an improvement in quality and quantity in their own work, 52% saw an improvement in the quality of their team's work and 38% saw an improvement in quantity. From a managerial point of view, that a positive result, especially considering that the interviewees did not have experience working remotely before the social/physical distancing measurement. Also, supporting that finding, 48%

and 38% of the participants said none of the aspects worsened during this period in their individual and team's work, respectively, and only 14% said their team's work got worse.

One possible explanation for that perception about the individual work compared to the team's work is that the interviewees were not used to working remotely prior to the social/physical distancing measurement, so they would almost always work physically together at the laboratory. Due to that sudden and involuntary change in behavior, the participants may need more time to get used to not literally seeing their peers work and assess solely the deliverable.

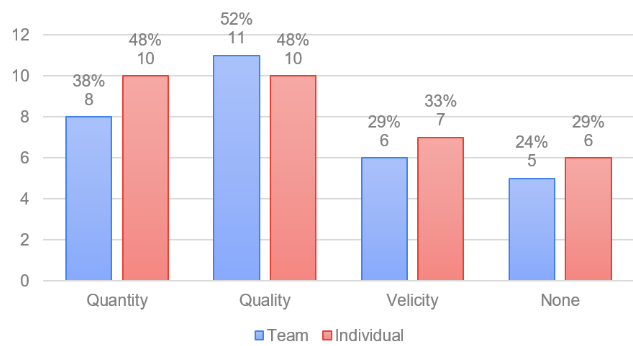

Fig. 5. Perception of improvement in the work done

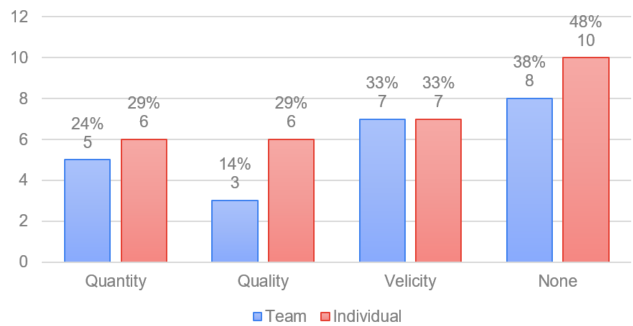

Fig. 6. Perception of worsening in the work done

In order to validate the results obtained with the questionnaire, we also got the perception of the researcher responsible for the academic production and solution development. In his evaluation of the results, the productivity increased substantially as well as the quality of the work done, needing less revisions and being more concise.

Finally, two other assessments were made to verify the performance of the group as a whole. The first was to compare the differences in academic production and solutions development compared to the previous year, 2019. The second is the comparison between what was planned in the original proposal of the solution development and what was actually achieved until the date of this publication. The results of those assessments can be seen below.

The development of the solution started on June the 2^{nd} and the assessment was made on August the 21^{st}, leaving 81 days of work to be analyzed. In this period, 24 activities were defined for the team to work on. Of those 24, three were not started yet and one is still ongoing due to lack of financial resource, since our funding is limited. Due to that, only 20 activities will be considered from this point forward.

Of those 20 activities, 10 (50%) were completed on time, two (10%) are still ongoing and are on time considering the proposed schedule, four (20%) were not delivered on time and the remaining four are already completed but did not have a predefined due date. The four tasks that were not delivered on time had no direct correlation with each other and were not sequential, so this delay did not affect much the development of the solution, even if the average delay among those was 10 days. Considering that before this project started this team had no prior experience working remotely and only had a small contact with agile development, this result was better than expected by the managers.

At last, the last parameter analyzed was the academic production and solution development compared to the previous year. Beginning with academic production, in 2019 were written 16 articles for conferences and congresses. Of those, one was not accepted and one was finished in 2020, so will not count in this analysis as completed. That means 87,5% of the articles written were accepted. This year, until August 15 articles are being written (including this one), one has already been finished and accepted and there are other five in the team's academic production backlog. If the same acceptance rate of 87,5% is applied this year, 19 articled will be published, meaning an increase of 5 articles. Even though in 2020 there are eight more researchers working in the UIoT group compared to last year, when there were 16, meaning an increase of 50%. Considering the others solutions the group usually works on, this year three dashboards were made, compared with only one last year, and two apps were developed and are fully functional. Last year none of the apps started were fully completed. This result is better than what the managers expected especially considering that in the beginning of the social/physical distancing period the work was barely being done.

V. Conclusion and Future Works

Due to the difficulty in measuring the productivity of a group, especially in a case such as this one, where we did not have any data prior the social/physical distancing period, the way around that problem was through a qualitative assessment. In order to do that, the perception of productivity was evaluated via an online and anonymous questionnaire and the results were validated using the available information about the project schedule and comparing the academic and solution production with the previous year. The results of that analysis pointed out an improvement in the quality of the deliverable as well as in quantity. Also, considering the social distancing measurement implied all researchers had to change completely how and where they worked, the results were better than what was expected at the beginning of the year.

Researchers who answered the questionnaire felt an increase in their productivity and quality of deliveries during the research period in isolation. Despite not needing to work fixed hours, the interviewees reported an increase in the number of deliveries and in the time dedicated to academic research. Activities are delivered on time for most respondents even though they have to divide their attention to care for elderly relatives or children and perform household chores. Most of the interviewees reported preferring to continue working remotely, saving commuting time, taking advantage of this time to rest or finish activities assigned to them.

Considering the results stated in the last paragraph, although the results of the questionnaire were inconclusive at first, it enabled us to get a priceless insight in the group perception of their own work and the new situation the Covid-19 imposed in all of us. Also, the assessed understating of productivity was essential to the continuous improvement work the group is starting from now on. It will enable us to better formulate the questionnaires as well as help create a sense of belonging withing the group, since everyone's perceptions are taken into consideration when assessing the productivity and quality of their own work.

Regarding the adapted product development model proposed and used by the UIoT team, the work was carried out up to the development part, with a TRL 3, which means the critical functions of software and hardware are still being tested at the laboratory environment. Therefore, future works may analyze the next TRLs, from the post development phase until the point the product becomes a fully commercial application. This would allow a comprehensive validation of the proposed methodological framework and provide improvements to it. Also, future works may continue and enlarge the productivity analysis by the use of periodical questioners and more quantitative tools as well.

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