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MANUSCRIPT TITLE:

# 3D printing technology and Internet of Things prototyping in Family Practice: building pulsoximeters during COVID-19 pandemic

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ABSTRACT

Family doctors can have an active role in identifying significant population needs and solutions. During COVID-19 epidemic, patient home monitoring with pulse oximetry has been a key aspect of care of patients. However, pandemics bring shortage medical equipment such as pulse oximetry. Through the local maker community in a matter of days four “smart” pulsoximeters were created and built. Following Internet of Things principles, the pulsoximeters were programmed to transmit recorded data through Wi-Fi, in real time, directly to the doctors. Each protype pulsoximeter served a family doctor during the pandemic. Building instructions were shared in maker-oriented websites, potentially leading to additional small-scale productions.

KEYWORDS

Covid19, Pulsoximeter, Internet of Things, Maker Culture, Medically Underserved Area doi:10.20944/preprints202005.0163.v1

MAIN TEXT

**Introduction**

Family Medicine aims to deliver new medical discoveries associated with important benefits to the general population, closing the gap between research and standard practice. Most biomedical research transferred at community level encompassed medicines and assistive technologies, with family medicine being the last receiver of innovation [1]. However new frontiers are opening up. The Internet of Things (IoT) is a system of smart devices connected to the Internet and communicating over a network [2]. In this context family medicine per se can become the starting point of innovative approaches.

The maker culture is a culture movement identifying people devoted to the creation of new devices and tinkering with existing ones, usually involving electronics and software programming [3]. Makers often aggregate in so called fabrication laboratories (often called fab labs) where experts in multiple technologies try to leverage their knowledge and skills [4]. Mastering technologies such as 3D printing, micro-soldering, electronic circuit design and production, and software programming is a key feature of this new generation of workers. Therefore, labs are spaces for innovation equipped with 3D printers, laser cutters, chemical reagents, and other machines with the capability of starting small-scale production of smart devices. The potential of these fab labs in family medicine practice is unknown. In this short article we describe an experience in which the maker community contributed to the development of a potential solution for family doctors to a relevant problem of patients with COVID-19 within the context of the COVID-19 pandemic.

**The problem**

The importance of pulse oximetry has dramatically risen during COVID-19 epidemic. Desaturation is often the only parameter signaling the initial stages of the interstitial pneumonia which characterizes this infection, and a severe deterioration of patient's conditions. Therefore, pulse oximetry is a valid solution to monitor disease of patients, rapidly identifying a decline in respiratory capacity and need for hospitalization [5]. It is also non-invasive and easy to use. Home care may benefit from telemonitoring with pulsoximeters, especially in times when a pandemic from a deadly and highly contagious virus suggests to avoid unnecessary home visits [6].

During the first weeks of pandemic, general practitioners faced an immediate shortage of pulsoximeters. Medical equipment vendors as well as pharmacies quickly ran out of most models. Even online shops estimated delivery times above the month. Most attempts to procure them failed, leaving patients and family doctors in need of home monitoring without this device.

**The assembly work**

Having some experience in digital modelling and fabrication, we considered assembling one. We researched available literature on the topic, ranging from academic studies on the algebraic calculations needed to measure saturation, to do-it-yourself websites reporting instructions for assembling electronic components. Free literature contained detailed background information to support the development of each piece of technology. Using prototyping boards, we assembled the electronics and designed a 3D printed shell. Open source libraries were implemented to add Wi-Fi capability. In fact, we anticipated that it was in the best interest of the patient to have a device automatically transferring information on saturation by email to the family doctor, in addition to showing the same information on a small screen embedded in the device. We also anticipated the importance of an adequate calibration. With the help of the fab lab network, a community of people with strong interest in sharing and collaborating on useful contribution to advancement of society, we developed a software for a streamlined oxygen calibration procedure, using certified pulsoximeter available in the market as gold standard. Observed data originated by our pulsoximeters were consistent with certified pulsoximeters. Furthermore, to increase our confidence on device reliability, before delivering the uncertified pulsoximeter to the patient, we re-evaluated each pulsoximeter against a certified oximeter on that patient (Figure 1). Other local fab labs, a 3D printing industry and single makers, provided feedbacks for improving the device and made some corrections to our original software. We were also asked for collaboration and advice to scale up the production. Most of these questions are unanswered. The role of local fabrication of smart devices in the context of an emergency should be further studied.

**Potential of local production**

The entire time to finalize an emergency pulsoximeter was 10 days. Given our naivety and production capacity, limited resource available and piloting-nature of the solution, we stopped after having assembled 4 pulsoximeters (Figure 2), one for each general practitioner working in our practice. Each family doctor then used the device for the remaining time of the pandemic accordingly to his or her preferences and needs, selecting patients eligible to use the device and benefitting most. Patients were informed of the unavailability of certified devices, and characteristics and limitations of the emergency device, including lack of certification, were carefully illustrated.

After assemblage, in the first two weeks, the emergency pulsoximeters assisted six patients. This small number pales in comparison to the number of patients at home in need of telemonitoring. We have published free open source detailed building instructions for the making community and those interested [7]. We disseminated information on the possibility of recurring to this emergency solution until mass production will provide certified pulsoximeters. However, the potential and feasibility of this emergency solution might be overlooked.

**Discussion**

Pandemics involve the whole world population, bringing shortage of key assets such as medicines or medical equipment. It is of crucial importance that the most up to date medical supporting life technologies are available to everyone who needs them. However, industrial production may need time to adjust to rapidly increasing demand. Internet has made available scientific knowledge at population level. This may provide an answer to large scale requests. General Practitioners have the capability of swift detection of the population medical needs and can oversee and coordinate the efforts of the local communities to address those needs. However, in order to rapidly finalize open source projects and scale up production of supporting life technologies, as well as deploying devices in different parts of the world, more expertise is needed than that usually available in a fab lab.

Adding a WiFi transmission may have been vital in reducing physical contact with an infectious patient. This feature is not usually available in pulsoximeters commercially available. Following current protocols, for each COVID-19 patient, a nurse with protective gear should daily reach the patient at home in order to measure vital parameters. This could be avoided by developing smart Internet of things medical devices, saving time and reducing exposition to the infection. Privacy issues discouraged us from using web-based data recording and elaboration, therefore email was chosen as the most accessible communication channel.

This experience suffers from a number of limitations. It is anecdotical. Despite we attempted to control for most anomalies due to personal characteristics, i.e. dark skin, differences in blood vessels or finger thickness, we cannot totally exclude them. Medical devices requisites, e.g. being waterproof, must be fulfilled. Measurement tools have to be studied in appropriate clinical studies to evaluate diagnostic accuracy and replicability of results. While we used a certified sensor for oxygen blood levels, the final pulsoximeter we assembled lacked certification. Against an emergency scenario, we favored a precautionary approach, measuring our devices against a certified device at individual level, and limiting the local production of pulsoximeters to few units.

## Conclusion

In times of emergency the ability of prototype development technology to adapt to new needs can be the key for addressing emerging challenges in reasonable times. Solutions can be provided by the industry compound. However new technologies can possibly support more delocalized answers. Health professionals, such as family doctors, can have an active role in identifying key needs and developing these potential solutions, which include ex novo fabrication. Advances in medical knowledge and modern technology are the key differences with middle-age epidemics, and we should take advantage of them.

## Declaration of interests

The author declares no conflict of interest.

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Figure 1: Comparison between a home-made pulsoximeter against a certified one

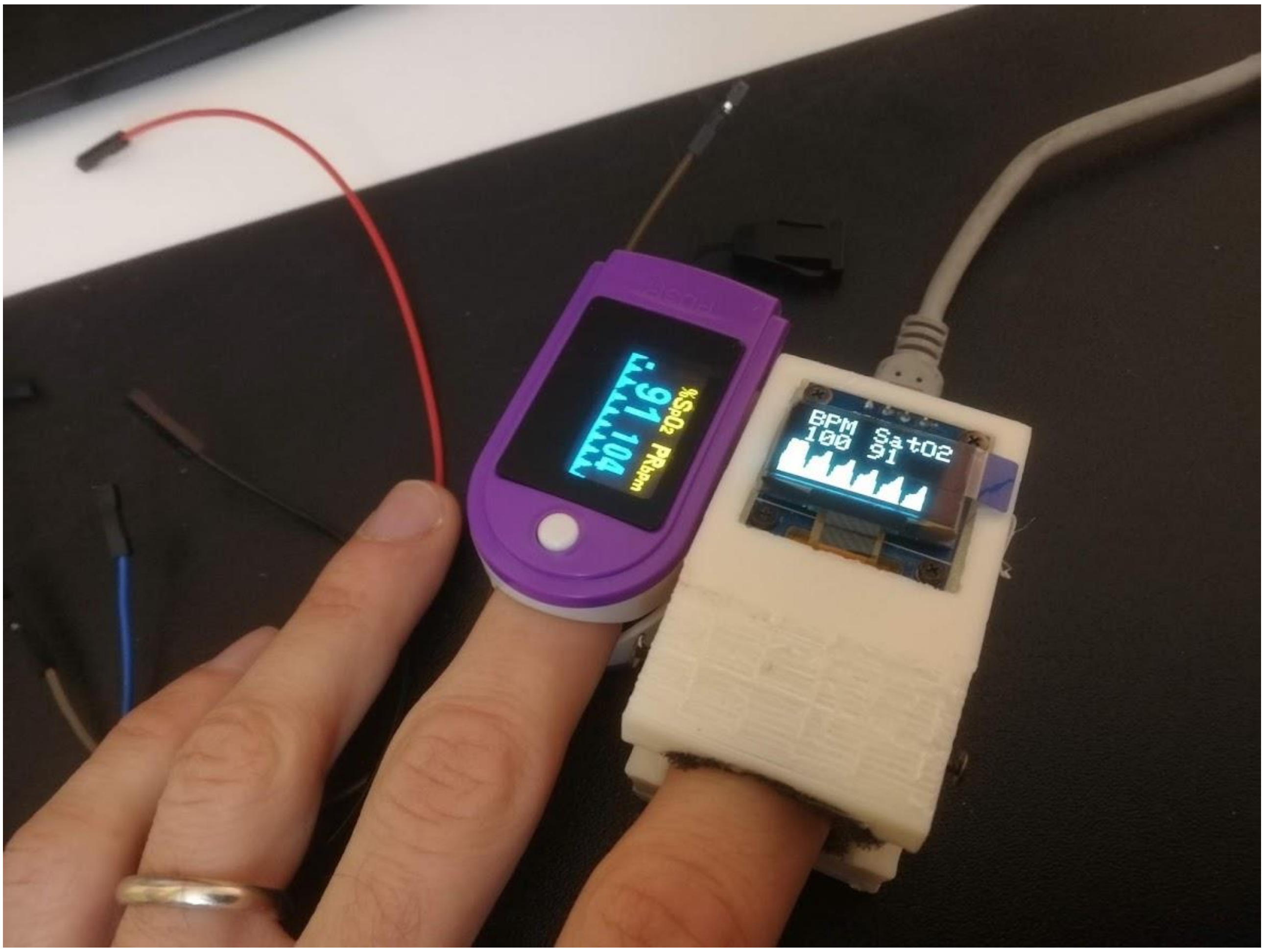

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Figure 2: The four pulsoximeters at final stages of production