Proxemic Interactions in Mobile Devices to Avoid the Spreading of Nosocomial Infection of COVID-19

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***Abstract*—Currently, people's daily lives are affected by the pandemic produced by the COVID-19. One of the main problem is the quickly and easy spreading of the virus. Healthcare workers are affected by nosocomial infections (also called as hospital-acquired infections) that exist in workplaces and more specifically, from health care equipment. In practice, the use of technology is quite common in health care settings. However, due to the touchability of mobile digital devices, their use contributes to nosocomial infections, according to several studies. Some applications based on tracking people have been implemented in order to facilitate Human-Computer Interaction (HCI) and preventing contamination of surfaces by people's hands. Notwithstanding, their use still presents limitations related to implementing applications to be used in some hospital environments, such as care rooms, laboratories, clinical workrooms. To overcome these limitations, we propose the use of interpersonal distances and proxemic dimensions (i.e., Distance, Identity, Location, Movement, and Orientation – DILMO) for implementing HCI with mobile devices that reduces their touchability. The aim is to facilitate the development of mobile apps with proxemic HCI, supported in a proposed architecture, to stop spreading of nosocomial infection of COVID-19 and others. To show the usability and suitability of our proposal, we present two prototypes of apps for mobile devices as proof-of-concept, using several combination of proxemic DILMO dimensions to model proxemic HCI that allow flexibility in interpersonal and devices-people interactions.**

***Index Terms*—Proxemic Interaction, HCI, DILMO, proximity, nosocomial infection**

I. Introduction

The pandemic produced by the COVID-19 has affected people's daily lives. One of the main problem is the quickly and easy spreading of the virus, that causes a huge quantity of infected people assisting to healthcare centers. Thus, nosocomial infections (also called as hospital-acquired infections) of COVID-19 affect healthcare workers (HCWs) in the workplace according to recent studies [1], [2]. This infection is defined as contamination during the process of care in a hospital and also it is considered as occupational infections among HCWs. HCWs use technologies in hospital, laboratories, intensive care units, and operating rooms; thus during any interaction with computers and mobile devices, they come into close contact with strongly contaminated devices.

Previous studies demonstrated drastic reductions of nosocomial transmission of COVID-19 thanks, in large part, to physical distancing among people in hospitals [3]–[5]. However, contamination of computer user interfaces and mobile devices, due to their touchability, are frequent in the clinical workrooms contributing to spread of COVID-19 [6]. Several studies suggest touchless interaction to avoid the contact of contaminated materials [7]–[10]. Touchless interaction has been used in operating rooms (ORs) during surgical procedures, notably to provide control of medical image analysis, such as the work proposed in [8], which uses the notion of proxemic and touchless interaction systems in surgical contexts. However, previous studies reveal that nosocomial transmissions is also a real problem for HCWs in other areas of the hospital, even beyond the OR [11], [12].

Mobile technologies in hospital are increasing in a way without precedent in different areas of the hospital. HCWs can interact in different contexts through electronic devices, such as personal mobile phones, tablets, and wearable technologies, to accomplish their daily tasks, based on specific Human-Computer Interaction (HCI). Some studies have emphasized that mobile devices are reservoirs for pathogens with potential to cause nosocomial infections [13]–[15].

In order to reduce the HCWs contamination through mobile devices, we propose the use interpersonal distances to develop mobile applications based on proxemic HCI, using combinations of proxemic dimensions – i.e., Distance, Identity, Location, Movement, and Orientation (DILMO dimensions). We are interested in handling interpersonal distances for interacting with mobile devices, according to different combination of DILMO dimensions. We are therefore seeking to develop new useful user interfaces, that allow HCWs to reduce the touchability of mobile devices and limit the spread of nosocomial infection of COVID-19. We also propose a development architecture based on mobile technology to support the easy construction of proxemic HCI for mobile apps. To show the usability and suitability of our proposal, we present two prototypes of apps for mobile devices as proof-of-concept, using several combination of DILMO dimensions to model proxemic HCI that allow flexibility in interpersonal and devices-people interactions.

The remainder of this paper is organized as follows. Related work is presented in Section II. A description of DILMO dimensions in medical environments is presented in Section III. The architecture to support development of proxemic mobile apps based on DILMO dimensions is described in Section IV. The details of prototypes and scenarios are presented in Section V. Finally, conclusions and future works are given in Section VI.

II. Related work

In this section, we present a review of studies that describe the difficulties and risks of HCWs using computer equipment in the workplaces and how HCI can be used to reduce such as risks. We also survey applications that show how proxemic DILMO dimensions have been used to implement interactions among digital devices and devices-people.

A. HCI to reduce the risks of nosocomial infection for HCWs

Today, HCWs are facing a difficult situation in the workplace because many of them have acquired COVID-19 disease during medical service [1]. The HCWs are exposed to a nosocomial infection that exists in a specific location, such as a hospital and more specifically from health care equipment. In fact, the use of technology is very common in health care settings however it is a difficulty for fully secure access to computer controls (sterilization for example) which increases opportunities to spread pathogens [11]. Previous studies have shown microbial contamination of computer peripheral like keyboard and mouse used to enter information in a care center during the workday [16]. Moreover, recent studies show that the use of mobile phones inside hospitals might serve as repositories of microorganisms that could be rapidly transmitted from the mobile phones to the HCWs' hands and therefore can help the transmission of bacterial from one patient to another person [17], [18].

Besides, Harvard University researchers published results of the simulation of a mathematical COVID-19 model [3], [19], which predicts that recurrent winter outbreaks will probably happen after the first, most severe pandemic wave; prolonged or intermittent physical distancing may be necessary until 2024. Therefore, it is vitally important to reduce the spread of COVID-19. Previous studies demonstrated drastic reductions in infections and deaths thanks, in large part, to the physical distancing among individuals [3]–[5]. Physical distancing in the health centers is important for HCWs. Several studies suggest that implementing physical distancing in the hospital helps to prevent nosocomial transmission of COVID-19 and ensures the health of HCWs to meet the hard challenge. For example, the study presented in [20], suggests the reallocation of mobile workstations, laptops, or desktops to private rooms that avoid all sources of contamination and clean surfaces such as keyboards and desktops frequently because COVID-19 can survive on surfaces for several hours.

Some studies have proposed the use of computer equipment in hospital environments based on touchless interaction to help decrease the risk of nosocomial contamination and prevent nosocomial transmission of COVID-19 [11], [21]. In particular, the work proposed by O'Hara in [8] uses touchless interaction and voice commands to control and manage imaging technologies within a surgical setting where touchless inputs might permit new kinds of interaction during surgery.

Touchless computer interfaces are widely used in ORs for decreasing opportunities for the spread of pathogens on computer controls and facilitating HCI [8], [11], [22]. However, the Health Informatics Journal [11] has recommended to explore the use of touchless systems in other areas of the hospital environment. Besides, touchless systems [7]–[10] have utilized Microsoft Kinect sensor, which produces motion tracking with far high accuracy. Notwithstanding, the studio presented in [23] demonstrates that mobile technologies could offer radiology residents the highest usability when employing touchless interaction.

All those previous mentioned works demonstrate the current interest for researchers and medical professionals to decrease physical interactions with computers to avoid spreading of infections. In this context, proxemic interactions can play an important role to implement HCI that reduce touchability of devices. Therefore, it is necessary to provide software architectures on mobile devices that incorporate DILMO dimensions for reducing the risk of cross-contamination with mobile devices.

B. Proxemic interactions in HCI

Proxemic interaction arises as a novel concept to improve HCI [8], [30], [47]. Proxemic interaction is derived from the social Proxemic theory proposed in 1966 by the anthropologist Edward T. Hall [48]. He described how individuals perceive their personal space relative to the distance among themselves and others. Thus, Hall's proxemic theory proposes four interaction zones [48]: (i) intimate zone, comprised between 6' and 18' of distance (0-50 cm); (ii) personal zone, defined by a distance of 1.5' to 4' (0.5-1 m); (iii) social zone, if distance is between 4' and 12' (1-4 m); and (iv) public zone, if distance is between 12' to 25' (more than 4 m). Researchers are therefore seeking to develop new useful and enjoyable interfaces based on proxemic interactions, which describe how people interact

TABLE I
SYSTEMS BASED ON DILMO PROXEMIC DIMENSIONS

Name	Scope	D	I	L	M	O
Marquardt et al. [24]	Framework	■	■	■	■	■
Ballendat et al. [25]	Application	■	■	■	■	■
Brock et al. [26]	Application	■	■		■	■
Brudy et al. [27]	Application	■	■	■	■	■
Cho et al. [28]	Application	■	■	■		
Garcia-Macias et al. [29]	Application	■	■	■	■	■
Grønbæk et al.(a) [30]	Application	■		■	■	■
Pérez et al. [31]	Application	■	■		■	
Sørensen et al. [32]	Application	■	■	■	■	
Cardenas et al. [33]	Framework	■	■	■	■	■
Ledo et al. [34]	Application	■	■	■	■	■
Dingler et al. [35]	Application	■	■	■	■	
Mentis et al. [8]	Application	■	■	■	■	■
Mojgan et al. [36]	Application	■	■	■	■	■
Rector et al. [37]	Application	■	■	■	■	■
Dostal et al.(a) [38]	Application	■	■	■	■	■
Dostal et al.(b) [39]	Application	■	■			■
Vermeu et al. [40]	Application	■		■		
Wolf et al. [41]	Application	■	■			■
Bhagya et al. [42]	Service robot	■	■	■	■	■
Kim et al. [43]	Application	■	■	■	■	■
Wang et al. [44]	Framework	■	■		■	■
Grønbæk et al.(b) [45]	Application	■		■	■	■
Grønbæk et al.(c) [46]	Application	■	■			■

with digital devices [25], [49], using five interpersonal physical dimensions or a subset of them: Distance, Identity, Location, Movement, and Orientation (DILMO dimensions). Proxemic interaction is a very interesting interaction technique that allows the user to control digital devices [24], [25], [34], allowing reducing physical contact with hardware without loss of semantic interactions. In the following we describe some works that have used different DILMO dimensions to implement proxemic systems.

DILMO proxemic environments, in which all dimensions are considered are described in [8], [25], [27], [29], [33], [34], [36]–[38], [42], [43]. The work presented in [33], illustrates how the proxemic dimensions can support interaction among entities (people and objects), with a context-aware framework. In [37], authors propose the use of the body-tracking capabilities of Kinect sensors to obtain the distance and react according to the location, movements, and orientation. DIMO proxemic environments are considered in the studies presented in [26], [44]. Games' actions are defined according to the distance, location, movements, and orientation of devices manipulated by children [26]. DLMO proxemic environments are presented in [30] in the context of cross-device games and cross-device interactions, while in [45] cross-device interactions are conducted by these dimensions to share information among digital devices. A DIL combination is presented in [28], in which a proxemic environment is described in the context of an application that allows the recognition of materials based on low-cost mobile thermal camera integrated into a smartphone. This application measures the physical distance between the camera and the material and recognizes a specific texture (identity). The application provides a tool that records the location of potholes in a road.

Studies based on DILM environments are presented in [32], [35]. The Multi-Room Music System proposed in [32] is a mobile app based on proxemic interactions that lets the user hearing the same songs playlist, while he changes his distance and location through the speaker arrangement in the house. Proxemic environments reacting to distance, identity, and orientation (i.e., DIO proxemic environments) are presented in [39], [41], [46]. In [31], a DIM proxemic environment is described in the context of a First Aid Mobile Application (FAMA). FAMA offers the rescuers the ability of obtaining emergency identification (identity) of an unconscious person, as the rescuers are moving toward the injured person's proxemic zones. Distance and location (DL) of people are considered in [40] to define different actions in an interactive display.

Table I summarizes the use of DILMO dimensions in the referenced studies. We also show the scope in which the work has been used. Most of them are specif applications and only three works are considered as frameworks to support the development of proxemic applications. In this work, we demonstrate that the combination of DILMO dimensions can be applied in healthcare applications, in order to reduce the touchability of devices. The development of these kind of applications is supported in a proposed development architecture, based on mobile technologies to gather the proxemic information (i.e., the measures of DILMO dimensions).

III. DILMO IN MEDICAL ENVIRONMENTS

In this section, we demonstrate how the combination of DILMO proxemic dimensions can be used to create appropriate proxemic HCI for applications in medical environments, to improve seamless interactions between digital devices and users, while reducing the risks of noscomial transmissions. Proxemic dimensions are captured from sensors, which means that a variety of hardware technologies can be substituted or combined for sensing proxemic information [24]. Thus, measures of DILMO dimensions should be gathered from the available technology (i.e., sensors) in mobile devices.

Table II shows examples of combination of DILMO dimensions in medical environments and the hardware of mobile devices required for sensing proxemic information from the environment. Currently, most mobile devices are equipped with a camera, GPS facilities, wireless connections as Bluetooth, and Bluetooth Low Energy Beacon (BLE) technology.

We characterize some DILMO combinations and how proxemic information can be obtained from mobile devices. Furthermore, we describe semantic information of such as combinations that can be used to create mobile applications for medical environments:

- **Distance (D)** is a physical measure of separation between two entities. The new capabilities of mobiles devices offer different way to sense proximity and estimate distance from images captured from the camera (e.g., based on mobile computer vision) and from BLE technology.
- **Identity (I)** is a term that mainly describes the individuality or role of a person or a particular entity. This proxemic

dimension is assigned based on entity identification. BLE use universally unique identifier (UUID) that allows application to assign an entity's identification. The identity can be also obtained using face recognition on mobile devices.

- **Location (L)** describes qualitative aspects of the space, where there is interaction among fixed entities (e.g., room layout, doors) or semi-fixed entities (e.g., furniture positions). GPS coordinates on mobile devices allow marking an approximate location of objects in indoor spaces.
- **Movement (M)** is defined as changes of position and orientation of an entity over the time. Although mobile devices are equipped with motion sensors, such as accelerometers, gyroscope, and gravity sensors, we propose to capture motion through the camera (with computer vision algorithms), since those motion sensors need physical contact to interact with HCWs.
- **Orientation (O)** provides the information related to the direction in which an entity is facing. It can identify the front of an entity (e.g., person's eyes, screen front). The user's orientation can be detected based on the camera and computer vision of mobile devices capabilities and using face detection algorithms.

TABLE II
DILMO MEDICAL ENVIROMENTS

DILMO	Description	Camera	BLE	GPS
D	Distance between HCWs and devices	✓	✓	.
I	HCWs' identity or device identifier	✓	✓	.
L	Medical equipment position	.	.	✓
M	HCWs Gesture	✓	.	.
O	HCWs' gaze or face orientation	✓	.	.
DI	Physical distancing between entities	.	✓	.
IO	HCW's orientation and identity	✓	.	.
DIO	IO in a proxemic zone	✓	✓	.
DIMO	IO in a proxemic zone and body tracking	✓	.	.

In the following, we describe some examples of DILMO combinations in medical service applications that allow limiting touch interactions. It is not described as an exhaustive list, some other DILMO combinations can be defined, according to the available technology and requirements of applications. Actually, the inverse condition can also be exploited: DILMO combinations can characterize the hardware necessary to implement medical applications on mobile devices, in which the user interaction with contaminated devices is avoided. Thus, it is possible to identify DILMO combinations according the available hardware or to decide which mobile hardware is needed to implement specific DILMO combinations.

- **DI** combination allows identifying specific HCWs (Identity) and their proxemic zones (according to Distance among them). This combination enables HCWs to keep physical distance with others using mobile devices. Moreover, the use of **DI** allows the development of applications that interact using the proximity between HCWs or between HCWs and medical device.
- **IO** combination allows facial recognition (Orientation) of authorized users (Identity) for access control using mobile computer vision, for areas such as laboratory, pharmacy, emergency rooms, and isolation rooms, for example, to access sensible patient information or private services.
- **DIO** combination offers HCWs the possibility to interact with information systems avoiding physical contact with computer peripheral. With BLE technology it is possible to estimate Distance between mobile devices and to get their Identities; while mobile computer vision allows sensing HCW's orientation and identification. This combination can avoid the usage of peripherals, which are difficult to sterilise and a potential source of contamination, such as mouses, keyboards, and smartphones.
- **DIMO** combination allows building mobile apps for gesture interaction (Distance, Movement, and Orientation) that help the HCWs (Identity) to manipulate information (such as images) displayed on the screen, using mobile computer vision and body tracking. DIMO applications provide more direct control of medical procedures based on gesture interaction captured with mobile computer vision.

These DILMO combinations are the base to develop some applications intended to reduce the spread of nosocomial infection of COVID-19 in hospital environments. In the next section, we propose an architecture aimed to support the development of such as applications, based on the basic technology of mobile devices.

IV. ARCHITECTURE TO SUPPORT THE DEVELOPMENT OF DILMO-BASED MOBILE APPLICATIONS

Our proposed development architecture, shown in Figure 1, is supported on an API and BLE libraries that allows developers to manage different social distances according to requirements of the specif application. Through the mobile devices sensors, the proxemic information is gathered (i.e., DILMO measures), according to the desired combination (see Table II). We describe each component of our proposed architecture as follows.

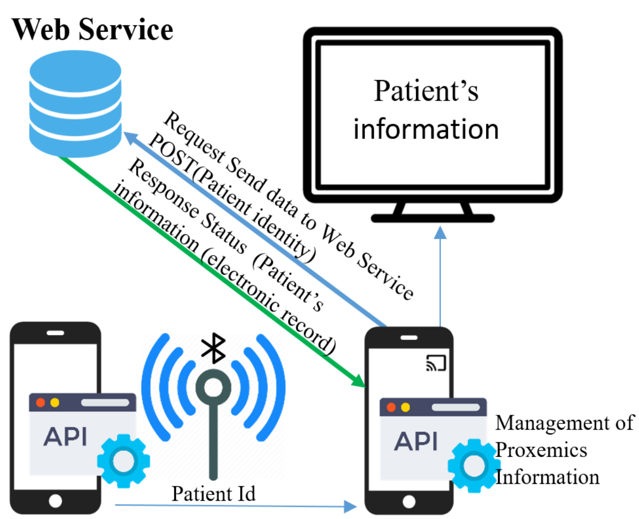

Fig. 1. Architecture to support development DILMO Mobile applications

A. Proximity: Virtual Bluetooth Low Energy Beacon (BLE) on smart-phone

The use of beacons to support human interaction is not new. The work presented in [31], describes the use of beacon BLE technology through a First Aid Mobile Application (FAMA). FAMA offers the rescuers the ability of obtaining emergency identification (identity) of an unconscious person protecting privacy of unconscious. The work presented in [50], shows how blind people or visually impaired users equipped with smartphones can interact with beacons in order to receive assistance. In that work, the resolving of proximity detection (distance) takes great relevance. This study shows the advantage of implementing BLE Beacon. The work described in [51], implements beacon to rescue persons caught in an avalanche (skiers). Authors propose the use of two physical beacons: transmitter and receiver, one for the victim and the other for the rescuer. In a rescue situation, the victim and a rescue group need to work, both individually and collectively, the beacon transmits an electromagnetic signal, allowing achievement of the goal. Due to the versatility and easy use of BLE technology, our proposed development architecture is mainly based in this capacity of mobile devices. It allows developing mobile application with BLE and other capabilities of mobile devices.

To create a virtual beacons BLE in a mobile device, it is required to use Beacon protocols. We employ the Java android library AlteBeacon [52], which allows to estimate the physical distance between two devices and catch their corresponding UUID (identity). In our architecture, mobile devices transmit string data to another mobile using BLE, which is processed in real-time through the API.

B. API for proxemic social interaction management

We developed an API[1], which lets developers define the proxemic zones required for implementing mobile application based on social distancing. The API was developed in Java, hence the `jar` files are provided to be added to the Android Studio platform.

Depending on the application to be developed, it will be necessary to define several proxemic zones (as the four proxemic zones proposed by T. Hall [48]). Through the API, developers are able to define and customize the size of the proxemic zones. It also offers methods that allow developers to obtain the proxemic zone of entities, based on the distance between mobile devices. The API offers methods to process DILMO information locally, without a connection to a server. However, connection to the server can be established according to DILMO conditions.

C. Web Service for storing patient information

The proposed architecture uses a web service, which has been created for experimental purposes. The patient information is provided according to client needs (health centres). We implement a post method that sends a patient key to a server from HCW's smartphone. The patient information is then returned by the server to the mobile phone, which in turns transfer that information by cast receivers to a screen in the room. The access to the web server and the screen should be configured in HCWs' mobile devices and it will be allowed according to the implemented DILMO combination. The interpersonal distances are locally managed by the mobile devices using Bluetooth and the API.

[1]The API and Documentation are available in https://.com/

V. Prototype: Proxemic Mobile Applications based social distancing POC

To demonstrate the applicability and suitability, in the medical area, of our proposal, we built two mobile applications with proxemic HCI, as proof-of-concept, which are based on some DILMO combinations. These applications illustrate how the need of reducing the spread of bacteria associated with nosocomial infections, can be approached, by avoiding computer's peripheral and mobile devices touching and maintaining physical distance among HCWs. The scenarios described with both applications give a better understanding of proxemic interactions in medical environments.

The first application, called *InZone-19 DIO*, allows careful social interactions in hospital environments, reducing physical contact with hardware and limit the spread of nosocomial infection of COVID-19. The second one, called *InZone-19 DI*, helps to keep physical distancing between two HCWs. Table III summarizes API's methods, AlteBeacon (AlteB) libraries and mobile vision methods from Android native libraries (APKs) that were implemented to build both *InZone-19 DIO* and *InZone-19 DI* applications. Our API considers the extraction of DIO values from smartphones or mobile devices based on the Android operating system by using Bluetooth and camera that the majority of smart devices have in their hardware configuration.

TABLE III
Methods Implemented

API/APKs/AlteB	Class	Constructor and Method	*InZone-19 DI*	*InZone-19 DIO*
API	ProxZone	ProxZone(0.5, 1.0, 4.0, 50.0)	✓	✓
API	Dilmo	Dilmo(proxzone)	✓	✓
API	Dilmo	setProxemicDistance (distance)	✓	✓
API	Dilmo	getProxemicZoneByDistance()	✓	✓
API	Dilmo	setProxemicDI(uuid,D)	.	✓
API	Dilmo	getProxemicDI(uuid)	.	✓
APKs	Frame	Builder()	.	✓
APks	Face	detect(frame)	.	✓
AlteB	Beacon	getId1()	✓	✓
AlteB	Beacon	getDistance()	✓	✓

A. InZone-19 DIO (scenario 1): Mobile app reacting to distance, identity, and orientation

In a health care scenario, where touchable interaction must be limited to the minimum necessary between HCWs and mobile devices, we use an appropriate subset of proxemic dimensions (**DIO**, as shown in Table II). DIO combination allows developing a mobile application which can help HCWs to obtain electronic patient record using a mobile phone without touching the mobile device.

To illustrate our scenario, we consider a positive COVID patient, who lies in a hospital bed. A mobile phone, with *InZone-19 DIO* installed, remains on the left side of the hospital bed, let's called it `patient device`. The `patient device` is acting as a virtual BLE beacon and shares identification by establishing a Bluetooth connection with the mobile devices of HWCs, let's called them `HWC devices`, which also is executing *InZone-19 DIO* app.

When an HWC is in the intimate zone or personal zone of the `patient device` (Distance dimension), and her/his face is oriented towards its camera (Orientation dimension), the identification of the patient (Identity dimension) is sent to the `HWC device`, which is in the pocket of the HWC. An application in the `HWC device` sends a request to the server, along with the identification obtained from the `patient device` by Bluetooth, asking to the web server for the whole information of the patient. Then, the HCW can read the patient's electronic records on the screen in the wall of the room, exclusively using proxemic interaction.

This scenario, shown is Figure 2, illustrates how proxemic interaction decreases the risk of nosocomial transmission of COVID-19, avoiding the physical manipulation of mobile devices and computer peripheral equipment in hospital rooms.

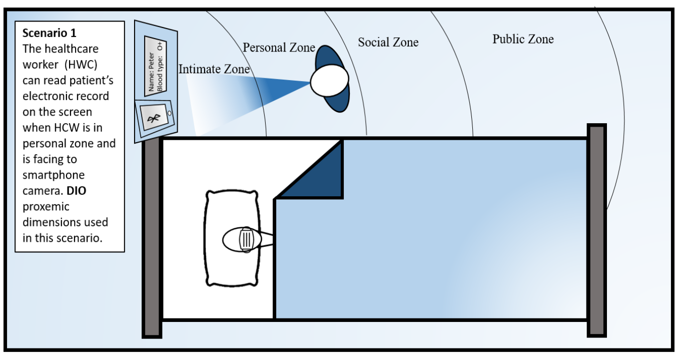

Fig. 2. Scenario 1: HWC reads a patient's electronic record from the screen using proxemic interaction in which the HCW avoid physical contact with his mobile phone.

B. *InZone-19 DI (scenario 2): Mobile app reacting to distance and identity*

An important strategy to limit nosocomial transmission is to implement *physical distancing* or avoiding close contact with others [20]. This *physical distancing* should be kept during the whole work day and in every where in the hospital. For example, during meal time, HCWs are encouraged to maintain *physical distancing*. To help maintain this requirement, we implement *InZone-19 DI* app, a **DI** proxemic application (see Table II).

To illustrate this scenario, we explain the use case shown in Figure 3: there are three HCWs in the hospital hall, which carry their smartphones in their pocket, running the *InZone DI* app that retrieves UUIDs around it. When a HCW invades the personal zone of another HCW, their smartphones trigger an alarm, which allows users to know that they are infringing the *social distancing*. In this way, the app creates a virtual security bubble which keeps physical distancing between two or more individuals only using smartphones.

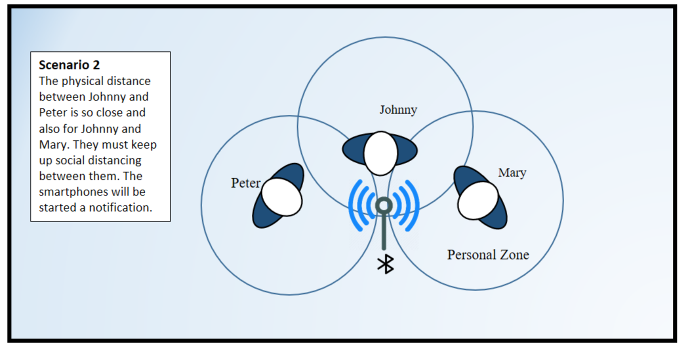

Fig. 3. Scenario2: Physical distancing between HCWs exclusively using Bluetooth BLE mobile devices.

VI. Conclusion

In this paper, we explore how proxemic interactions can exploit the capabilities of mobile devices to the needs of the healthcare sector improving HWCs interaction on mobile devices. Based on the proxemic dimensions (i.e., Distance, Identity, Location, Movement, Orientation – DILMO), it is possible to implement proxemic HCI that reduces the touch-ability of mobile devices. To support the development of mobile applications based on proxemic HCI, we also propose a development architecture, lying in mobile devices technology and an API.

We describe two scenarios based on combinations of DILMO dimensions, which help to limit physical contact and touch interaction with mobile devices without loss of semantic interaction using interpersonal distances. Both applications were developed with the proposed architecture, which allows developers making suitable several combinations of DILMO to each scenario.

With this research, we hope to inspire other researchers to build more mobile applications that help to stop the spread of nosocomial infections.

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