Contactless Physiology Radars to Promote Healthy Ageing via Remote Tracking: The Need for IoT Context

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Abstract: In recent years, the use of high frequency radars to promote the contactless monitoring of physiology parameters of cardiorespiratory nature has seen an impressive progress pushing for the creation of clinical experiences beyond the telecommunications engineering field. In this position paper, we argue in favour of combining the expertise of IoT and smart home research that paved the way for remote digital health in the last decade, to foster a paradigm shift in healthy ageing an independent living promotion by means of disruptive support technology that may overcome privacy invasiveness, discomfort, and usability issues.

1 INTRODUCTION

The promise of contactless physiology sensing for health has been around for years. With an interest that was revamped by the efforts of research teams around the world, the private sector is starting to pave the way for a productive market niche that is called to fill an existing gap no other technology covers smoothly.

Radio Detection and Ranging (in other words, RADAR) has been a long understood technology, with industrial success in areas as vast as marine and air navigation, military/defence, law enforcement, autonomous driving or even in civil engineering. It is only under the research initiatives of teams such as Dina Katabi's and their approach to wireless signals that use cases for physiology metrics have been starting to see the light in the last 8-9 years (Adib *et al.*, 2015). In fact, due to the nature of the technology, counting on sensors that give insight on position and peed is clearly aligned for the development of gait assessment studies throughout the world (Gambi *et al.*, 2020; Abedi *et al*, 2022), of interest not only to euromotor disorders, but also to a bigger frailty perspective. When entering cardiorespiratory metrics, an even more disruptive perspective beyond movement was established, since contactless physiology by means of radar is called to offer significant cost reductions, use case adaptation and signal quality features which could coexist with ubiquitous health wearables established in the last decade. Back in 2016, and focusing on contactless only, reviews like that of Naziyok, in Germany (Naziyok *et al.*, 2016), started to highlight how radar technology began to emerge as a consistent competitor against other technologies such as ballistocardiography (BCG), depicting pilots and proofs-of-concept taking place in clinical domains out of the lab. A transition to radar-based spin-offs and successful use cases built for pathologies such as Parkinson's suggest a promising landscape (Kabelac *et al.*, 2019), for a far more versatile technology than its vibrational-based counterparts. Works such as

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millimiter wave approach of (Antolinos *et al*., 2020) set a general comparison between several contactless physiology sensing technologies, covering not only BCG, but also video-based recording and thermal-based technology among others. Growth experienced by the radar business has been also notable in the in-cabin monitoring for the automotive field, transitioning from lab experiments (Lázaro *et al.*, 2021) to full datasets sponsored by key automotive industries (Yoo *et al.*n 2021) such as Hyundai. For vital signs, the link between biomedical engineering R&D groups capable of processing the data and clinical assessment teams at healthcare institutions narrowing down use cases applies more than ever before, with sleep health and pneumology offering a productive landscape for the years to come (Yen *et al*., 2022). Respiratory health, sleep health assessment and datasets set up for palliative care use cases (Schellenberger *et al*., 2020; Michler *et al*., 2019) are only a few examples of the possibilities that radar physiology will bring in the short term. Current reviews already illustrate engineering efforts incursion into the clinial domain, underlining the different frequencies and operation modalities even within the field of radiofrequency sensing for physiology (Paterniani *et al.*, 2023), reinforcing the message that contactless physiology radars are now explored hand in hand with medical specialties experts. In this paper, we build the case for radar physiology that could suit healthy ageing paradigms. In this paper, we illustrate physiology metrics that are a reality in our contactless physiology approach, already integrated into our IoT cloud services, and outline how contactless physiology may support clinical supervision of relevance to the older adult user.

2 BACKGROUND

A physiology radar is a device that utilises the transmission and detection of radio waves emitted towards a person, inferring vital signs from the reflected waves. Range, speed, and ultimately, physiology waves are inferred by deploying one of the main existing processing strategies available in radar sensing: a) Impulse-Radio Ultra Wideband (IR-UWB), b) Doppler Continuous Wavelength (CW) and Frequency Modulated Continuous Wavelength (FMCW). The recent review of Paterniani's team (Paterniani *et al.*, 2023) illustrates how all these paradigms, with their strengths and drawbacks, have successfully started to implement use cases of interest to the clinical domain.

The market shift experienced within electronics since the 2000s, where chipsets, components and electronic modules have steadily experienced reduced mass production costs and dimensions, is no exception to the radar domain. In practical terms, this has meant that radar transmitters and receivers (antennas) prepared for different operation regimes have undergone a transformation that today feeds off-the-shelf consumables ready for research exploration with versatile characteristics (radar modality, frequency of operation, bandwidth). Such a growth has spurred lab efforts for long out of reach due to high costs. Sensors (radars) are nowadays eligible for customised component adaptation, use case scenario definition, and important work on the underlying algorithms to denoise, filter and convert demodulated high frequency radar waves into actionable physiology signals that can be fed into healthcare monitoring pipelines.

In parallel, the advent of IoT cloud smart home settings and businesses thriving in the domain of remote health is a reality established to a point never foreseen before the recent COVID-19 pandemic. IoT services that are nowadays offered in the fields of efficient energy management, domotics and smart homes have steadily built a case for remote health that is no longer science fiction, as seen in examples with gait analysis, indoor position for ambulatory pattern characterisation, sound and magnetic-based indoor location (Guimaraes *et al.*, 2016), gamified remote physiotherapy, and connected telemedicine metrics or smart home data to analyse health decline taken at home (Alberdi Aramendi *et al.,* 2018) , to name a few. Undoubtedly, the ubiquitousness of mobile phones in our society is also to blame, since the fact that virtually any person can carry a powerful tiny computer, anytime, within his or her pocket, has redefined how technologies may support data collection, data transmission, information access, interpretation, health self-awareness and engagement or ownership of the processes ingrained in the so called 4P medicine (predictive, preventive, personalised and participative). In essence, what an IoT sensor infrastructure at home offers, is a means of getting to monitor contextual information of particular interest. And this is, of course, a monitoring infrastructure that goes hand in hand with cloud services and communication devices that enable the storage, integration and processing of the remote sensor's data. Countless examples of IoT ecosystems for Digital Health exist already in behavioural metrics, mobile-supported health supervision and ambient intelligence with or without the integration of wearable sensors.

The demographic challenge continues to be present today in Europe and worldwide. Life expectancy has significantly increased in recent years, and it is a trend still observed, posing the need to strengthen societies in which people not only live longer, but more independently, inclusive and prepared to cope with the health deterioration and comorbidities that accompany the process of ageing. The clear push obtained within projects under the European Active and Assisted Living (AAL) framework in the form of outcomes on tech development has significantly interconnected the private and public sectors, to which remote wearable health played a key role in different implementations. However, when it comes to technologies to support Healthy Ageing, while the promise of gadgets unlocking physiology monitoring insight is remarkable, currently existing paradigms pose certain concerns of usability, privacy-invasiveness and activity disruption, long identified in research literature.

2.1 Radar Principles

Conceptually speaking, any contactless radar deployment can operate easily leveraging any preexisting remote health sensor infrastructure counting on an IoT cloud, communication protocols, and a processing pipeline that can elaborate on raw data to offer clinical insight by means of apps, dashboards, and assessment interfaces. Figure 1 depicts a simple 3-step dataflow (RADAR physiology, IoT cloud and Digital Health platforms or user interfaces).

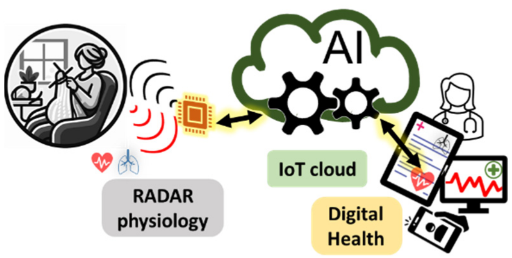

Figure 1: Radar physiology sensing (data flow depiction).

But in order for this to happen, radars need to be understood. In general terms, radar physiology principles, especially under the successful FMCW approach, can be characterised in the following manner:

1. High frequency waves are emitted from the radar toward the targe subject, with an intrinsic frequency and modulation pattern defined at emission. The electromagnetic wave is a complex signal that encodes information in the form of an amplitude and a phase
2. Signals that reach the target subject are reflected back, establishing a dependency between original waves and any changes in the movement of the target. In particular, physiology research will address the dependency between radar signals and the thoracic (or cardiothoracic) cavity movements.
3. Analysis of the received waves combines Doppler effect principles to extract range (distance) and changes (speed) with complex radiofrequency wave demodulation of the in-phase (I) and quadrature-phase (Q) components to infer changes with respect to the emitted signal
4. Advanced spectral analysis techniques and filtering proceed to tell apart cardiac, respiratory signals and movement or noise artifacts.

Figure 2 shows a representation of such signals where inhale/exhale breathing cycles are captured alongside cardiac activity.

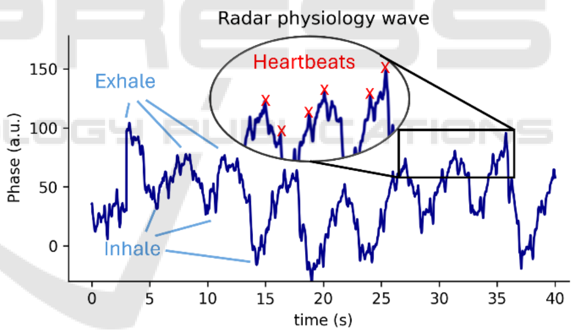

Figure 2: Depiction of radar (phase) signals encoding physiology data along time. Own work, inspired by (Adib *et al.*, 2015).

While the process seems overly simplistic, antenna design, directionality, the control of parameters such as field of view (FOV), maximum range, frequency modulation paradigms, signal filtering, multiple-input multiple-output for an improved performance and spectral analysis are engineering science fields in themselves.

In the FMCW characterisation outlined, for instance, multiple reflections off target come into play, posing the challenge of filtering those that come from the target of interest even when at rest or in the absence of any movement.

2.2 The Need for Context: IoT

To this date, the so claimed smart radars for contactless physiology are not smart. In this work, we argue in favour of the use of IoT sensors to make contactless radar-based physiology a reality. Our rationale does not try to invalidate any of the progress done with embedded computation within radar host boards, since computing at the edge (close to where the sensors are, as opposed to cloud) is called to transform the future of remote sensing by optimising the use of computing or networking resources while lowering the environmental impact of cloud computing, often overlooked. On the contrary, our perspective is that of leveraging the vast expertise in IoT for remote tracking to provide contextual information which could render radiofrequency sensors for physiology smart. If so, such a challenge calls for the coupling of radar technology with IoT sensors that can already inform about subject's activities, subject's position, presence of other individuals in range, behavioural metrics, or environmental conditions at measurement time.

2.2.1 IoT Examples

IoT encompasses a range of technologies that have been around for more than two decades now. Some examples illustrate how sensors deployed in a remote environment complement existing tracking paradigms. On the one hand, IoT could be in charge of enabling communication between sensors and processing infrastructure. On the other hand, IoT facilitates an interface to which engage with the tracking, or the resulting assessment. More interesting, though, is the use of IoT sensors to add context. Context supports such health tracking paradigms offering information of relevance to the core metric clinically targeted.

This is the case, for instance, of (Pang *et al.*, 2023) who in the context of COVID-19 were able to combine wearables for cough monitoring with IoT sensors to add an environmental dimension to the assessment.

Other examples in chronic respiratory issues exemplify how the IoT, either as seen statically in a house or as a portable concept relying on mobile phones and wearable devices (Escalona et al., 2023) offer novel perspectives such as personalised asthma symptom progression alongside individual exposure to low air quality.

3 USE CASE SCENARIOS

Our work in the framework of the Tecniospring UPTAKE project, has made progress in the following lines.

First, a protocol for the collection of a radar-based physiology dataset alongside reference physiology signals and a predefined set of actions measured by IoT sensors was established. This was done in collaboration with the Department of Computing Engineering of a University campus, recording sessions that lasted 20-30min each, in what we called a smart office (contact sensors in doors, windows, environmental metrics). Ongoing work aims at the open access publication of the dataset and protocol description to enable contactless physiology data quality assessment (to be published 2024). Labelled datasets promote the use of machine learning techniques to improve signal filtering, detect context or operation regimes, so that processing can be optimised to the activity, position or movement being performed by the subject.

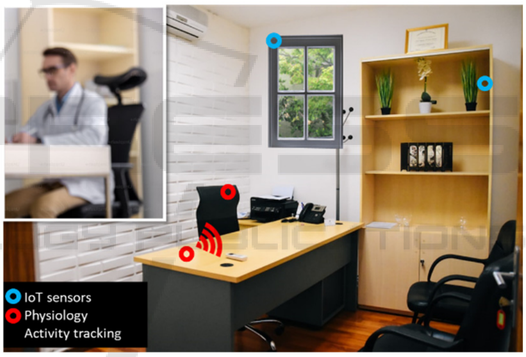

Figure 3: Smart office environment for contactless physiology acquisition and IoT activity tracking.

In turn, the usage of complementary sensors (with data that could also be made openly accessible) enables the understanding of how context awareness fosters efficient radar measurement and subsequent processing. How data from different sources (radar and IoT) needs to be combined is not yet entirely clear. However, the understanding of context variables such as where the target subject is located, whether he or she is standing or resting, and whether there is activity with profuse movement, offers valuable input. This input guides how different processing algorithms should operate to optimally retrieve the physiology data, or whether certain data entries should be discarded altogether. IoT gateways (i.e. devices that connect multiple IoT modules or sensors) are capable of establishing a single access point where data would count on synced clocks.

Those data points can therefore be used in rules and logic for processing dataflows, as triggers to activate different sensors around the smart home context or even with more in-depth analysis instructions that would establish a link between an activity and a monitoring regime.

The idea that multiple low-cost radar sensors can accompany a smart environment (house, office, or clinic) to characterise different situations and rooms must progress in line with IoT support metrics that will avoid noise, irrelevant data capture or even inefficient operation regimes deployed continuously on places without relevant target or action taking place. From a smart office, it is easy to start approaching protocols that would turn a doctor's office into a smart one equipped with intelligent triage taking place in a seamless way, or adding objective physiology metrics to the routine visit acquired while in a sensor-equipped waiting room, optimising time and resources. With validation only seen as a first step beyond sensor manufacturer's claims, the potential of contactless physiology for healthy ageing becomes only tangible when outlining use cases tackling a specific pathology (or serving the needs of given medical specialties).

Two of them are illustrated in the following subsections.

3.1 Medical Equipment Supporting Physiotherapy Sessions with Contactless Physiology

Neuromotor disorders with higher incidence in advanced ages, fractures compromising mobility, traumatic brain injuries (not necessarily narrowed down to the older adult) and post-surgery procedures leading to prolonged hospitalisation, are paradigms where rehabilitation plays already a crucial role in the recovery of affected patients within the clinical institutions.

Digital health has successfully demonstrated success cases in which technology supports the rehabilitation processes. This comes, for instance, in the form of assessment metrics and logs throughout the process, engaging platforms to distribute guidance materials or even prescribe and monitor exercises, gamification assets to spur adherence to treatment or even visual based performance metrics on exercise compliance. Physiology, however, is usually not embedded in the process due to the need to allocate extra resources to a dimension that may increase protocol complexity and assessment. While stress tests, exercise metrics or routine lung function measurements or electrocardiography are resource-consuming tests only applied upon request.

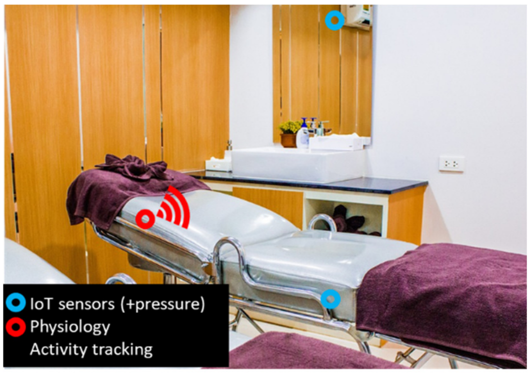

Figure 4: Smart medical equipment (bed) provided with radar physiology sensors for hassle-free biosignal acquisition. IoT sensors (pressure mat and contextual metrics on the room) complement the data.

If radar physiology sensors demonstrate the fulfilment of high data quality standards comparable to gold standard medical equipment, the embedding of radar sensors to medical beds (medical equipment) offers a promising access to a physiological dimension that takes place seamlessly for the patient. All of a sudden, the clinician can access a range of data that delivers cardiorespiratory insight, enabling to establish baseline measurements and pre/post exercise assessment that may unveil recovery progress or underlying issues such as bad sleep health or respiratory function concerns.

3.2 A Radar-Equipped Smart Home to Support Independent Living

A smart home is a residence that utilises technology (sensors, actuator and network infrastructure) to enable a set of control and action features over house facilities or services. For instance, energy efficiency and consumption management, smart curtains and blinds, surveillance technology, intelligent water supply or consumer electronics equipped with monitored usage (fridge, water dispenser) are market services that have flourished under the domain of smart homes. In turn, from a research perspective, more disruptive IoT sensing approaches are tackling activity recognition which could contribute to a better understanding of behavioural metrics. When approaching remote physiology metrics for digital health, radiofrequency sensing technology embedded in furniture, walls or ceiling emerges as a great step forward.

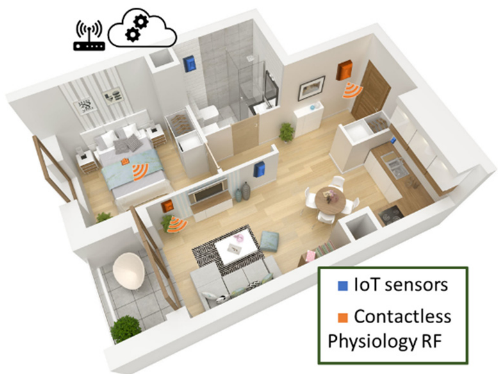

Figure 5: Smart home IoT environment where IoT sensors (blue) and contactless physiology radiofrequency monitoring (orange) devices coexist to enhance context awareness and cover a full picture of remote health tracking at home.

This technology offers sensors that would enrich existing behavioural monitoring paradigms, complement wearable-based studies already tackling biosignals or, even better, overcome some of the limitations identified in established technologies. In other words, the contactless hassle-free viewpoint of physiology radars, could end up superseding audiovisual behavioural surveillance in terms of privacy-invasiveness, or overcoming concerns raised by wearable usage on discomfort, daily activity disruption and device charge/discharge routines, both contributing to end user engagement, usability and adherence. In Figure 5, a smart home schematic is shown in which multiple radar physiology sensors (orange) are deployed throughout various dwelling spaces, while they coexist with IoT sensors offering action context or activity metrics.

4 CONCLUSIONS

This position paper aimed to illustrate how our current research work on contactless radars for physiology can pave the way for healthy ageing. Discussion within our partner healthcare networks unveiled straightforward applications of radar physiology that are intrinsic to the contactless nature of the proposed sensors, e.g. for neonatal intensive care units, burn units and wards, and first responder emergencies. In the face of a significant range of new businesses emerging in the radiofrequency sensing domain, unresolved issues on measuring technique, filtering procedures and hardware design constitute main research topics where progress is called to set the future of the sensing paradigm in the following years. A trend of significant cost reduction and promising results have helped radars secure their share of Digital Health technology solutions research. The fact that people are nowadays surrounded by WiFi and 5G radiofrequency communication antennas (2.4GHz, 5GHz frequencies respectively) have built the case for an unexplored remote sensing opportunity working at operating regimes that pose no health concern to the user. Those are devices that have made it into our homes, not necessarily posing significant maintenance or setup concerns other than first-time connectivity service arranged by telecom service providers. Continuous exposure to radiofrequency power is not to be taken lightly, though, when a shift of paradigm is implied going from broad internet/mobile service coverage to a targeted remote health tracking where people are expected to spend a considerable amount of time under radiofrequency signal power (with frequencies operating 1-2 orders of magnitude above communication standards). With respect to monitoring, unresolved issues still remain on the hardware to be adapted for different uses (bed, chair and low range vs high range environments), processing issues on multi-person environments and other agents (e.g. pets), and generalisation concerns when moving far from quiet scenarios (bed, seated) where great disturbances are not foreseen.

While the technology struggles to find its place outside the telecommunications engineering labs and signal demodulation procedures are further improved, we advocate for a shift in perspective that acknowledges the advances observed in IoT ecosystems for remote health. The IoT market is prepared to embark into the process of integrating a contactless physiology technology while offering the support infrastructure and context awareness that will make radar vital signs clinically viable.

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Conflict of Interest: Authors Miquel Alfaras and Zouhair Haddi are employed by NVISION, an R&D company developing IoT and Digital Health services.

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