Gait analysis with a wireless radar network for early detection of Parkinson's Disease

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***Abstract*—Anticipating the detection of Parkinson's Disease is critical to delay its effects. This paper presents the design of a radar network for the early-detection of Parkinson's Disease analyzing gait impairments. The preliminary results of the radar network show that gait biometrics, and gait asymmetries linked to Parkinson's Disease can be clearly identified in the micro-Doppler signature.**

***Index Terms*—Parkinson's Disease, PD, gait monitoring, LFM-CW radar, wireless, radar network.**

I. Introduction

Parkinson's Disease (PD) is a neuro-degenerative disorder that affects 2% of the population over 60 years old [1]. The neuropathological diagnosis is the only unequivocal PD diagnosis. However, it cannot be practiced while the patient is alive [1]. Still, it is possible to perform a reliable PD clinical diagnosis while the patient is alive. After the diagnosis, it is important to monitor the patient to study the effect of the treatment and to prevent risks such as falls. Therefore, the challenge arisen concerning PD is three-fold. First, it is necessary to anticipate the detection of PD to delay its effects (early detection). Second, it is necessary to increase the accuracy of the diagnosis of PD. Third, it is critical to monitor the patients with PD to prevent risks.

In the last few years, new non-invasive trends have appeared in the literature using biometrics to detect and monitor PD. Some of these biometrics are tremors [2]; gait [2]; speech [3]; handwriting [4]; and eye movements [5]. The technologies presented in this paper focus on the early detection of PD based on gait impairments.

Early detection of PD based on gait impairments should not be limited to a clinical environment, because clinic measurements focus on the patient's capacity, while domestic measurements focus on the patient's performance [6]. The evaluation should be continuous, in a domestic environment.

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All the technologies implemented to assess PD diagnosis based on the biometrics present in gait cannot be applied in domestic environments because of their limitations. Inertial Measurement Units (used in [2]) have limited batteries and are uncomfortable. Video-cameras and infra-red sensors (used in [7]) invade the subject's privacy, and are vulnerable at obstacles and low-illumination environments. On the contrary, radar technologies are capable of continuous unobtrusive measurements in low-illumination environments even with obstacles [8].

Radar technology has already been used to monitor gait with promising results [6], [9]. However, there are no direct applications of radar technology for early detection of PD.

In this paper it is proposed the design of a radar network for PD early-detection based on monitoring gait impairments. The radar network will determine some metrics associated with PD [10], [11]. The requirements of the system proposed in this paper are evaluated and listed, and the node is presented and validated.

II. Gait monitoring using radar

Gait is analyzed using the micro-Doppler signature of the target. The micro-Doppler signature represents the velocity of all the moving scatterers of the human body (torso, head, limbs, etc.). The micro-Doppler signature of a person walking away from the radar is shown in Figure 1d.

The graphs shown in Figure 1 are obtained using an in-house software presented in [12]. This software simulates a radar sensor measuring people performing different tasks. The recordings are obtained from the CMU Graphics Lab Motion Capture Database [13]. The location and the working parameters of the radar sensor can be configured. Thus, it is possible to consider all the aspects related to gait measurement using radar. Moreover, this software is capable of separating the micro-Doppler signatures of the different body parts. Therefore, it is possible to obtain very accurate information about the gait.

There are two main stages that repeat twice in a gait cycle (once per step). They are represented in Figure 1a, and reflected in the micro-Doppler signature. During the stance stage, one foot accelerates while it is elevated from the floor.

The velocity of this foot is maximum (5 m/s) when it passes below the torso. The foot decelerates before holding back in the ground. The signature of the torso (Figure 1c) represents the velocity of the target. The signature of all the scatterers combined (obtained in real-life measurements) is shown in Figure 1e.

Several metrics present in gait that are related to PD [10], [11] can be extracted from the micro-Doppler signature: step time, stance duration, and gait velocity [9]. In addition, the micro-Doppler signature should reflect gait asymmetries are usually associated with PD [14].

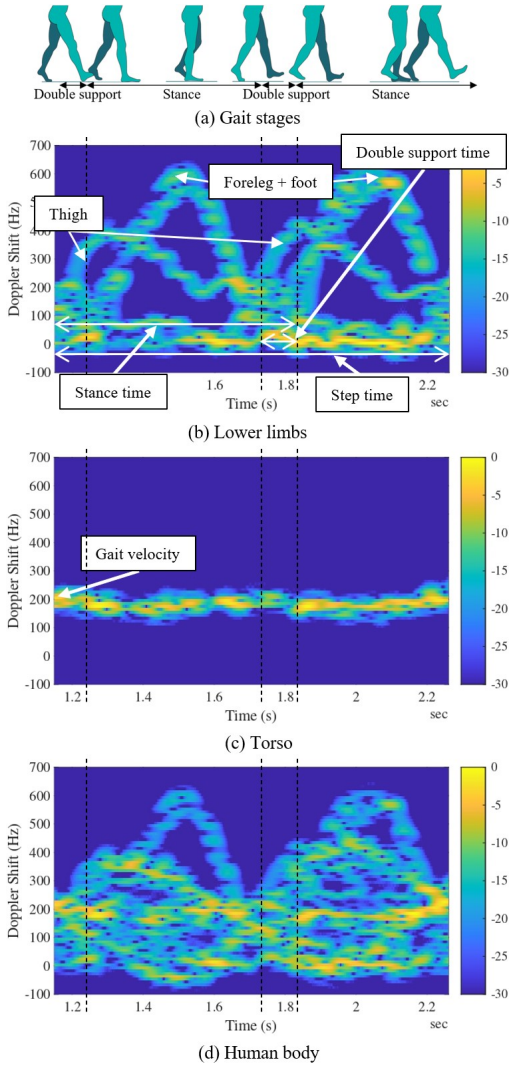


Fig. 1: Simulation of the micro-Doppler signature of the human gait (represented in (a)) focusing on: (b) lower limbs, (c) torso, and (d) complete human body. Some metrics are included in the signatures. It is used the recording of subject 2 of [13]. The radar simulated is a 24-GHz LFM-CW radar with chirp time $T_c = 625\mu$s, and bandwidth $B = 1.4$GHz.

III. Radar network. Requirements and deployment

Prior to analyzing gait in a domestic environment using a radar network to early-detect PD, it is necessary to validate the performance of the network in a controlled environment. Thus, a radar network is designed to measure patients performing the Timed Up and Go (TUG) test [15], a clinical test currently used to detect PD. At the TUG test, the patient stands up from a chair, walks 3 m away from the chair, turns around, walks 3 m back to the chair, and sits down.

The node location is presented in Figure 2. The deployment of the radar network benefits from the wireless connection of the nodes with the processing unit. The processing unit calculates the micro-Doppler signatures, and calculates relevant metrics for PD detection.

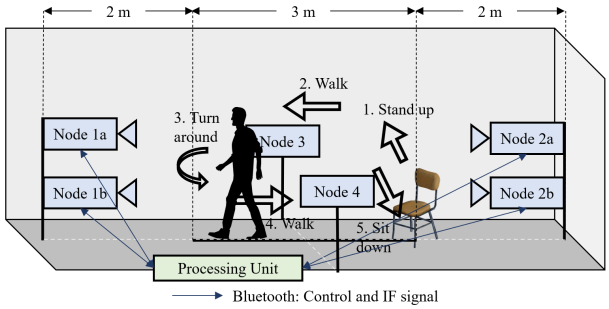


Fig. 2: Measurement environment with a target performing the TUG test. The system must work in small rooms such as the ones in a hospital. Nodes 1b and 2b are 0.4 m above the ground, and nodes 1a, 2a, 3, and 4 are 1.2 m above the ground.

IV. Node design

The nodes must fulfill the following requirements:

- Compact system: Frequencies above 24 GHz.
- Low-cost system: Linear-frequency-modulated continuous-wave (LFM-CW) radars (functioning principle summarized in Figure 3). The frequency difference between the transmitted and received signals (the beat frequency f_b) is proportional to the range R.
- Measurement range: The measurements must be carried out in the environment shown in Figure 2. Thus, the field of view (FoV) of the antennas should be $\vartheta \approx 40°$.
- Maximum radial velocity: The micro-Doppler signature must represent all radial velocities below 5 m/s: the highest radial velocity of a person's foot walking towards the radar, as shown in Figure 1.
- Continuous interrogation: To observe the maximum radial velocity, it is necessary to have the maximum update rate, i.e. process all the sweep intervals.
- High SNR.
- Wireless communication protocol: The communication between the nodes and the processing unit must be wireless. It is selected Bluetooth.

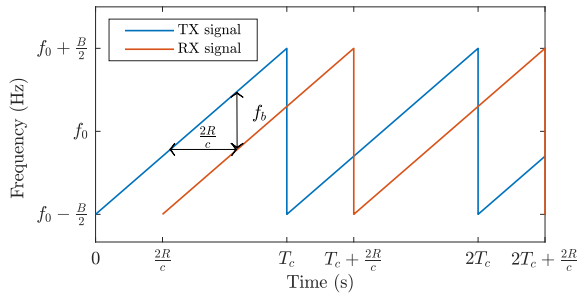


Fig. 3: Working principle of LFM-CW radar. The range of the target R is proportional to the beat frequency f_b: the frequency difference between the transmitted and received signals.

A. Node working conditions

The parameters optimized are the chirp time (T_c), the central frequency (f_0) and the bandwidth (B).

The chirp time determines the maximum micro-Doppler frequency that can be measured ($f_{d\,max}$) [8], which is related to the maximum radial velocity $\nu_{r\,max}$ = 5 m/s ($f_d = 2f_0\nu_r/c$):

$$f_{d\,max} \leq \frac{1}{2T_c} \Rightarrow T_c \leq \frac{c}{4f_0\nu_{r\,max}} \tag{1}$$

where c is the speed of light. Notice that larger chirp times increase the SNR because the integration time increases.

The target should appear in the region where the noise of the system is flat, above the corner frequency f_c. The bandwidth is set so that the minimum range $R_{min} = 2$ m is observed at $f_{b\,min} \geq f_c$. Thus, the required bandwidth is:

$$R = \frac{f_b c T_c}{2B} \Rightarrow B \geq \frac{f_c c T_c}{2R_{min}} \tag{2}$$

B. Microcontroller requirements

The sampling frequency f_s is determined by the maximum beat frequency of the IF signal ($f_{b\,max}$) ($f_s \geq 2f_{b\,max}$), which depends on the maximum range of the radar ($R_{max} = 10$ m) as shown in Eq. 3.

$$R_{max} = \frac{f_{b\,max} c T_c}{2B} \Rightarrow f_s \geq \frac{4BR_{max}}{cT_c} \tag{3}$$

The sampling frequency is set to about $f_s = 300$ ksps to reduce the processing burden.

The figures of merit of the node are shown in Table I.

V. Implemented Design

The radar node is based on the radar MMIC Infineon BGT24MTR11 [16]. It is implemented in two stacked PCBs that contain the radar antennas, the IF signal conditioning stage, and the microcontroller unit (MCU) ST Microelectronics STM32WB15CC. The radar node is configured to achieve the figures of merit shown in Table I. The node samples the IF data, preprocesses it, and sends the captured samples to a processing unit via Bluetooth without losing interrogations.

TABLE I: Node figures of merit.

Parameter	Value
R_{min} (m)	2
R_{max} (m)	10
$\nu_{r\,max}$ (m/s)	5
ϑ (°)	40
Central frequency f_0 (GHz)	24
Bandwidth B (GHz) (Eq. 2)	1.4
Chirp time T_c (μs) (Eq. 1)	625
Sampling rate f_s (ksps) (Eq. 3)	125
Continuous interrogation	Yes

The micro-Doppler signature is calculated and represented real-time at the processing unit. The micro-Doppler signature is computed using a 100 ms window. During this time it is assumed that the gait of the target does not experience any major changes. The micro-Doppler signature is also filtered to remove the static clutter.

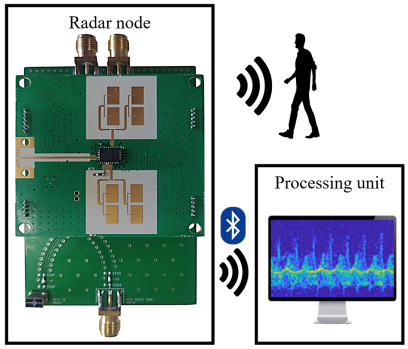


Fig. 4

Fig. 5: Radar node PCBs and processing unit with a real-time display. The node dimensions are 50x75 mm^2.

VI. Results

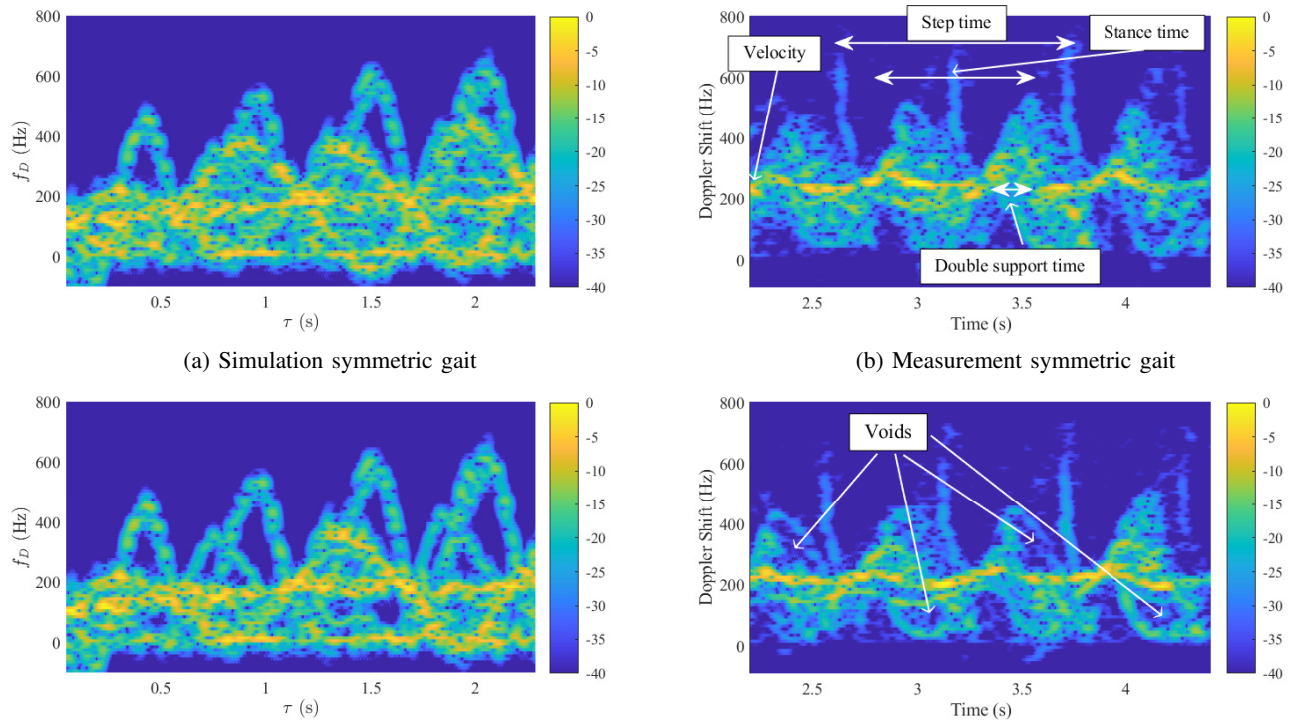
It is simulated and measured a human target walking away from a node placed 1.2 m above the ground in the environment shown in Figure 2. The target was recorded and simulated walking normally, and emulating gait impairments related with PD. The resultant micro-Doppler signatures are shown in Figure 6.

The gait biomarkers can be calculated automatically using the processing techniques introduced in [9].

Gait asymmetries linked with PD are also observed in the micro-Doppler signature. These asymmetries are observed as *voids* in the micro-Doppler signature of the limb which is not moving. The comparison of the *voids* generated in the simulation and in the measurements is shown in Figure 6c.

VII. Conclusion

This paper presents the design of a radar network for the early-detection of Parkinson's Disease analyzing gait impairments in a controlled environment. The basis of the network are defined, and the nodes are tested, obtaining results that show gait biomarkers asymmetries related with PD.



(a) Simulation symmetric gait

(b) Measurement symmetric gait

(c) Simulation asymmetric gait (emulating PD)

(d) Measurement asymmetric gait (emulating PD)

Fig. 6: Micro-Doppler signatures of (a) and (b) a healthy person, (c) and (d) a person emulating PD. (a) and (c) are simulations obtained using the recording of subject 2 of [13]. (b) and (d) are measurements. In both simulations and measurements, the radar node is placed 1.2 m above the ground using the configuration shown in Table I.

The design has been made with the objective of evaluating gait to early-detect PD, but can be extrapolated to other scenarios. For instance, once implemented in a domestic environment, the system presented could be applied for monitoring progression, and medication response to diseases with symptoms present in gait, such as PD and Amyotrophic Lateral Sclerosis.

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