Analysis of Micro-Doppler Signature of Humanoid Robot Motions for Health Monitoring

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***Abstract*—For last two decades, many approaches have been investigated for continuous health monitoring of the human. However, most of these solutions require sensors in constant contact with the human. In this paper, we demonstrate that it can be achieved without contact by investigating the micro-Doppler (m-D) signatures from the human. To achieve reliable and repeatable measurements, we utilize the NAO robot from Aldebaran Robotics. The robot is capable of different motions such as dancing, walking, limping and falling. A Vector Network Analyzer (VNA) is utilized to transmit signals to the scene with the robot. Received signals at VNA are processed by Short-Time Fourier Transform (STFT) to achieve m-D signature then human gait will be distinguished.**

***Index Terms*— Humanoid robot, micro-Doppler (m-D) Signature, Vector Network Analyzer (VNA).**

I. Introduction

DETECTING human motions (e.g., walking, limping, falling) without physical contact with the human objects plays an important role in a number of applications especially in health monitoring for senior citizens in long-term care facilities. In [1]-[2], conventional methods utilize devices attached to the patient’s body. These may be uncomfortable or impractical. A non-invasive monitoring system can be ideal to monitor continuous without requiring any assistances.

In this paper, we propose a system to remotely monitor and detect the human motions. The NAO robot provided by Aldebaran robotics is utilized to process four human motions, namely walking, limping, standing and falling on ground. Two 10 GHz horn antennas are used to transmit and receive a continuous wave (CW) signal through Vector Network Analyzer (VNA). To analyze the m-D signature, a joint time-frequency transform such as Short-Time Fourier Transform (STFT) is performed [3]. Different types of human motions can be identified and distinguished from the m-D spectrograms.

In the next section, the details of the proposed system are provided. We present some experimental results in Section III, and finally our findings in the conclusions section.

II. Proposed system for humanoid robot motion detection

We show the proposed system in Fig. 1, where a radio-frequency continuous wave signal is transmitted and reflected by the NAO robot. Two 10 GHz directive horn antennas are isolated by an absorber to eliminate the cross talk between them. One of them is connected to one port of the VNA to transmit the signal to the NAO Robot, while the other antenna is connected to the other port of the VNA to capture the reflected signal from the robot. A personal laptop is connected to the VNA by an Ethernet cable to access the received data.

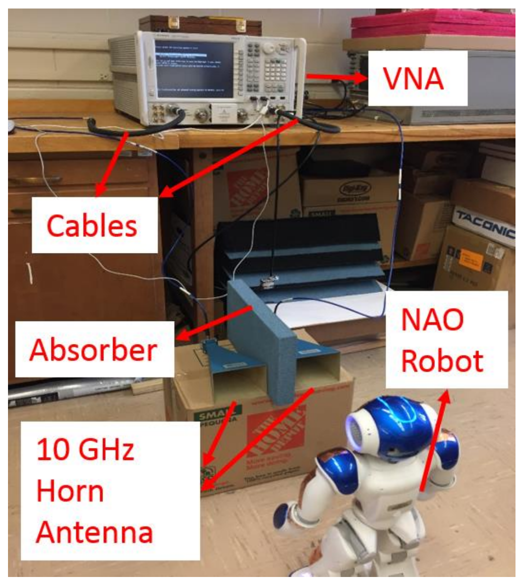

Figure 1. Proposed system for humanoid robot motion detection

In this paper, we leverage from the realistic movement and extensive gait customization capabilities of the NAO robot to ensure dependable motions for observations. We first program the robot for three human motions, namely regular walking, limping, and falling on ground. The company provides a well-defined algorithm for walking at different speeds. However, there were no features available for limping and falling on

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ground. We modified the walking algorithm to achieve these motions. For limping, the stride length of the right leg is reduced to 1 cm from 0.1 cm, the frequency of the right step is decreased to 10% of the original, and the right foot step height is reduced from 2 cm to 0.5 cm. Additionally, a body roll of 5 degrees in the x, and 7 degrees in the y direction are added to mimic the instability of a limping human being. In order to replicate a falling motion, the robot is programmed to stiffen all joints at once which halts all stability maintenance programs. A forward fall was ensured by forcing the joints at each ankle to move abruptly to an angle of 57.30 degrees (1 radian) such that the robot was past its anterior tipping point.

The Short-Time Fourier Transform (STFT) as shown in (1), is employed to determine the m-D signature from the robot.

$$STFT\{E_{radar}(\overline{r}(t))\}(\tau,\omega)=\int_{-\infty}^{\infty}E_{radar}(\overline{r}(t))h(t-\tau)e^{-j\omega t}dt \quad (1)$$

where $E_{radar}(\overline{r}(t))$ is the measurement data at the received data at each instant and *h(t)* is a time-limited window function, which determines the resolution of the STFT.

III. Experimental results

In the first experiment, the robot stands for 2 seconds and starts to walk for 5 walking cycles. Fig. 2 shows the m-D signature of the walking NAO robot. The Doppler signature reveals an oscillating pattern with nearly identical amplitudes between the left part and right part on the robot. From m-D signature, we can see that the robot is walking in 5 walking cycles with the maximum Doppler signature of 50 kHz.

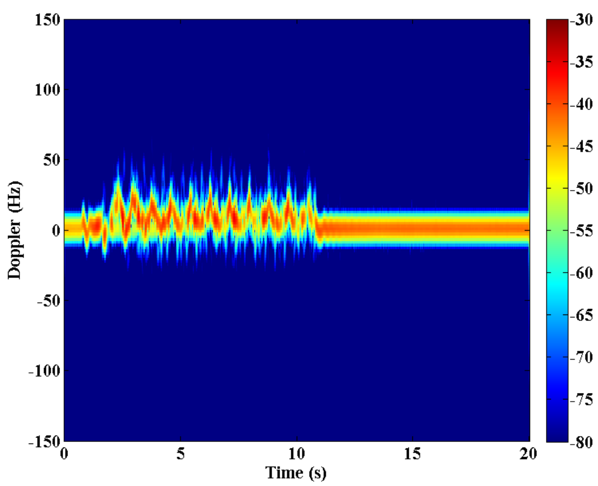

Figure 2. Micro-Doppler Signature of Walking Robot

In the second experiment, the robot stands for 3 seconds and starts limping by dragging the right foot for 11 walking cycles. Since the right foot was constrained, the sharp fluctuations in Fig. 2 are attributed to the left leg. Since the right leg is moving a miniscule distance exceedingly slowly, the Doppler signature of the right leg is invisible. There is a marked difference between the regular walking and limping as observed in Fig. 2 and Fig.3, making it trivial to detect an abnormal walk.

In the last experiment, the robot stands for 8 seconds, walks for 2 cycles and falls on the ground. Fig. 4 begins with 0 Hz which corresponds to standing, and transitions to regular walk. When the robot falls, the Doppler shift immediately spikes over 100 Hz. Since the fall motion is a much more rapid motion, the Doppler signature is much higher than the regular walking or limping. Its abrupt ending makes it unmistakably different from any other motion.

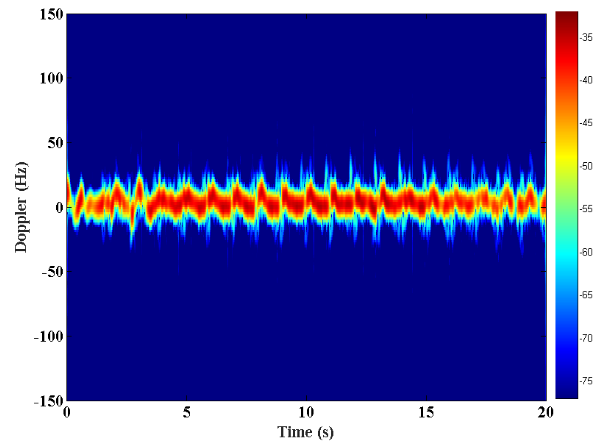

Figure 3. Micro-Doppler Signature of Limping Robot

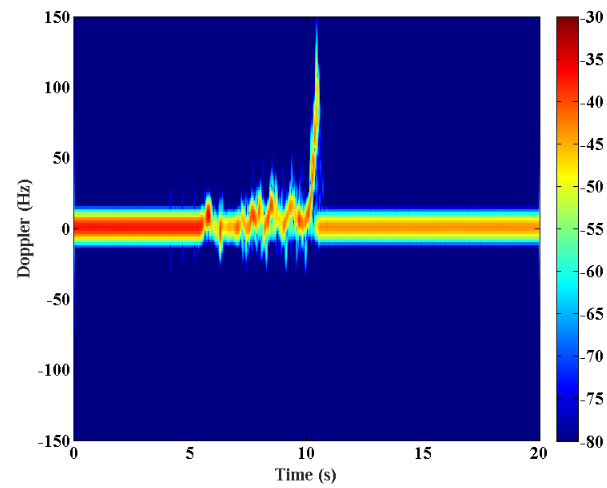

Figure 4. Micro-Doppler Signature of Falling Robot

IV. Conclusion

In this work, we propose the system to detect and distinguish motions of a humanoid robot. Based on m-D signature, periods of regular walking, limping and falling can be distinguished from one another.

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