Real time indoor presence detection with a novel radar on a chip

D. Deiana, E.M. Suijker, R.J. Bolt, A.P.M. Maas, W. J. Vlothuizen, A.S. Kossen
Radar Technology
TNO
The Hague, The Netherlands
daniela.deiana@tno.nl

***Abstract*—A novel FMCW radar on a chip operating in the 24 GHz band has been used for presence detection in an office environment. Real time detection of small movements (i.e. typing) has been demonstrated. A comparison of the performances of the radar sensor and of the traditional intelligent lighting PIR sensor has been carried out. While the radar is able to detect a movement of 1 cm along the radial direction, the PIR sensor can detect mainly larger movements along the tangential direction, showing the complementarity of these two sensors. Both sensors have a reaction time of less than 200 ms.**

Keywords—FMCW; real time detection; radar on a chip; motion detection; intelligent lighting; PIR sensor

I. INTRODUCTION

Energy efficiency and development sustainability are keywords in a modern society, which can project itself to the future only through an eco-sustainable process. This concept is reflected on the choices made by the industries that aim to become the major changers of the lighting market. The lighting industry is therefore facing a huge transformation, driven also by the rapid progress in LED lighting and semiconductor technology. Industry aims at making lighting systems more compact, efficient and intelligent. Nowadays intelligent lighting sensors are based on passive infrared (PIR). These sensors are very sensitive: they can detect human motion within a large detection area; however, they cannot detect successfully a person that is sitting in an office reading, typing, or watching a video, thus without making large movements with the arms or the body. Another example of a missed detection are the PIRs installed in a conference room where people are watching the screen without moving. After some time the lights go off because the PIR does not detect any presence.

Radar sensors, on the other hand, can detect the slightest movement of the human body, i.e. breathing, speaking, typing. Such sensors integrated in an intelligent lighting system, could overcome the problems encountered by PIR sensors, and give more detailed information on location where the movement takes place (measured as distance from the sensor). However, in order to fulfill all the requirements, such sensors need to be very small, low cost, low power and low energy consumption. In the framework of the European project EnLight [1], TNO has designed and developed a novel radar sensor on a chip, which operates in the ISM 24 GHz band and is FMCW based. The radar has been tested in an office environment, where one or more people were performing regular office tasks, such as reading, typing or talking. A comparison of the sensors performances has been carried out as well.

A short description of the radar is presented in section II. Section III describes the functioning of a PIR sensor. Measurement setup is presented in section IV. Signal processing is described in section V, while a comparison of the two systems is presented in section VI. Conclusions are presented in section VII.

II. RADAR DESCRIPTION

The novel FMCW radar consists of three components: a commercial ARM microcontroller, an in-house developed MMIC front-end and printed circuit board (PCB) dipole antenna array. It operates in the 24 GHz ISM band, with an allowed bandwidth of 250 MHz. The transmitted frequency sweep is generated by a voltage controlled oscillator (VCO) which is controlled by a ramp voltage from a digital to analog converter (DAC) circuit. The received signal is directly converted to IF with a double sideband mixer without a low noise pre-amplifier. The antennas have an average beam width of 50º in both E and H planes and an average gain of 10 dBi. This antenna configuration requires a metal plate at λ/4 in order to increase the front-to-back ratio. The output power of the MMIC is equal to -10 dBm. Considering the antenna gain, the simulated output power is equal to 0 dBm, far below the emission limit for this frequency band (20 dBm EIRP).

The radar is shown in Fig. 1 and a block diagram of the system is shown in Fig. 2. A detailed description of the radar system with all its components is found in [2].

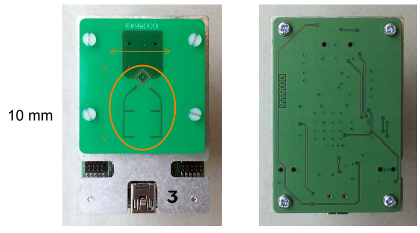

Fig. 1. 24 GHz FMCW radar. Top side view showing the chip and the two antennas (left); bottom side view (right).

978-1-4799-4195-7/14/$31.00©2014IEEE

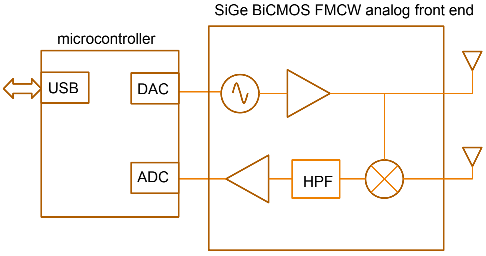

Fig. 2. Block diagram of the FMCW radar system.

The microcontroller is the NXP LPC1769, an ARM Cortex-M3 CPU based, with up to 64 kB of data memory, 10 bits ADC @ 128 kHz. It can collect at most blocks of 64x128 samples at a time. The sweep lasts 512 µs, with a PRF = 1.95 kHz. With an integration of 128 sweeps, a maximum velocity of 6.1 m/s is detected. The maximum range is 19.2 m.

III. PIR SENSORS

A passive infrared sensor detects changes in heat flux. A human body is constantly exchanging heat with the surrounding environment, due to temperature difference. The peak of the human radiation lies within the IR region, at 9.4 µm, and it radiates isotropically. A PIR sensor is made of pyroelectric material, which generates energy in response to a change in temperature. Detectors are often available in dual or quad-element versions. Dual-element detectors can subtract ambient temperature, reducing false alarms. Fresnel lenses are used for optical focusing. A scheme of human motion detection is shown in Fig. 3.

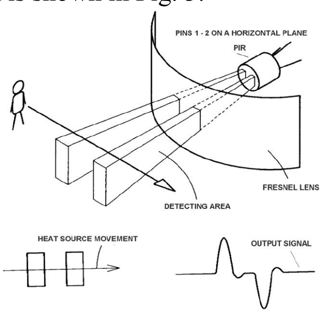

Fig. 3. Scheme of a PIR response to human motion [3].

It is important to notice that PIR sensors can detect correctly tangential movements, while radial movements cannot always be detected.

The PIR sensor used in the measurements is an off-the-shelf product, the Panasonic EW- EKMC1601111 [4]. The sensor characteristics are summarized in TABLE I.

TABLE I. PIR SENSOR SPECIFICATIONS

Item	*Value*
Detection Range	5 m
Temperature difference	4ºC
Detection area (XY)	> 80º
Detection zones	64

IV. MEASUREMENT SETUP

In a first phase only radar measurements have taken place in an office room with two desks and in a small conference room where more people were present. In the office the radar has been placed at a height of 3 m, with boresight along a vertical line towards the keyboard.

In a second phase a PIR sensor has been placed next to the radar, at 3 m height. Both sensors had to detect small arm movements, sitting still and typing. A schematic drawing of the office, with the sensors footprint is shown in Fig. 4.

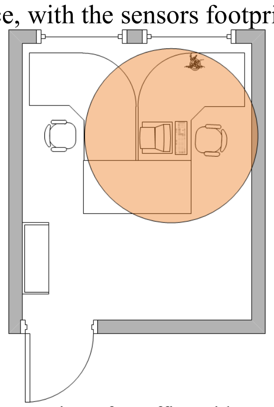

Fig. 4. Top view of an office with two desks. In orange the footprint of the radar and the PIR detector.

In order to test the sensitivity to false alarms of the systems, a small plant with moving branches due to a fan has been placed on the desk, along the sensors' boreside direction.

V. REAL TIME SIGNAL PROCESSING

At the moment signal processing is carried out with Matlab, taking into consideration the volume of data that the microcontroller can handle.

The sweep repetition interval (SRI) is equal to 512 µs. The buffer in the microcontroller can collect up to 128 sweep per time, resulting in a data acquisition time of 66 ms.

Two FFTs are performed to obtain a Range-Doppler matrix. The microcontroller takes 38 µs to carry out a 64 points FFT. Considering the worst case, where all computations are done serially, the microcontroller acquires and calculates a range-doppler matrix in less than 80 ms. The timings of the various operations are shown in TABLE II.

TABLE II. MICROCONTROLLER OPERATIONS

Operation		*Time*
Raw data acquisition	128 x 512 µs	66 ms
64 points FFT	38 µs	
128 range FFT	128 x 38 µs	4.9 ms
32 Doppler FFT	32 x 199 µs	6.4 ms
Total time		< 80 ms

The main requirement imposed for intelligent LED lighting is a reaction time of 200 ms. Given the computational power of the microcontroller, a detection decision must happen at most after two range-Doppler blocks have been processed.

Due to the scarcity of space allowed in the microcontroller, a simple amplitude detector has been implemented. The algorithm is developed based on two assumptions:

1. The position of the target to be detected is within 3 predetermined range cells (calculated based on the distance between the radar and the desk);
2. The radar has to detect typing movement. This corresponds, on average, in Doppler to a few Hertz.

The detection algorithm is briefly described here after.

A block of 128 sweeps is collected. The raw data is converted to range-doppler plot through two FFTs. A Hanning window is applied only in range. In Doppler no windowing is applied in order not to smear out the signal around the zero-Doppler, where the typing speed cells are located.
Based on the two assumptions, a target is to be found within two 3x3 matrices of range-Doppler cells (both positive and negative Doppler). The remaining area is considered background. An average of these two areas is collected and saved. After at most two range-Doppler blocks have been processed, these two averages are compared. If the target area has a value of at least 13 dB higher than the background area, a detection takes place and a signal is given to the lamp in order to switch on. A time frame where typing takes place is shown in Fig. 5.

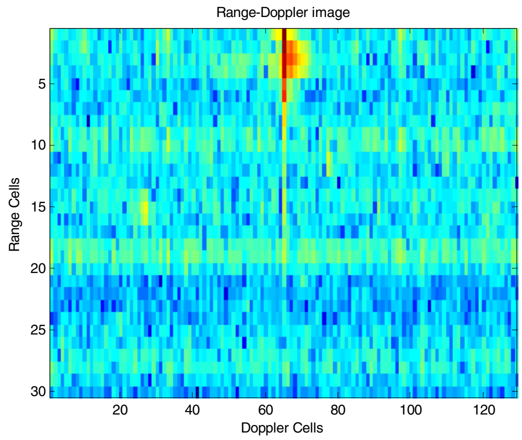

Fig. 5. Processed range-doppler frame while typing.

The algorithm detects the slightest movement of a finger (along the radial direction there is a finger movement of 1 cm). However it has not been set to detect a person that is completely still. Breathing modulates the beat note and a peak in the 0.4 Hz region (average human breathing rate) can be seen. This type of detection is beyond the goal of the present study.

This detection algorithm is very sensitive and neither false alarm nor missed detection (defined as the slightest finger movement) has been recorded.

Several tests have been carried out making different movements, besides typing, in order to test the missed detection. When a person moves the arms in the air, the signature appears in the range-Doppler plot as energy in correctly located range position, but smeared along the whole Doppler, due to the long integration time. This energy is averaged over an area much larger than the target area, allowing having always a difference of at least 13 dB between the two processed areas.

VI. COMPARISON OF PIR AND RADAR DETECTIONS

During the measurement, a person is sitting still in front of the monitor. Then the hands are placed on the keyboard and typing starts. An alternation of typing and not typing takes place. The result of this measurement is shown in Fig. 6. In green is shown the radar signal of a specific range cell in time. Radar detections are in red, while PIR detections are in blue. A zoom-in of the first detections is shown in Fig. 7. While the radar detects the whole typing period, the PIR detects only few occasions, i.e. when there is a lateral movement of a finger to press ENTER or TAB. Both sensors do not detect breathing. However in the last part of the range plot in Fig. 6 the breathing pattern is clearly visible.

The last PIR detections are those due to the hand movements to take the mouse. The radar algorithm had already been stopped by then.

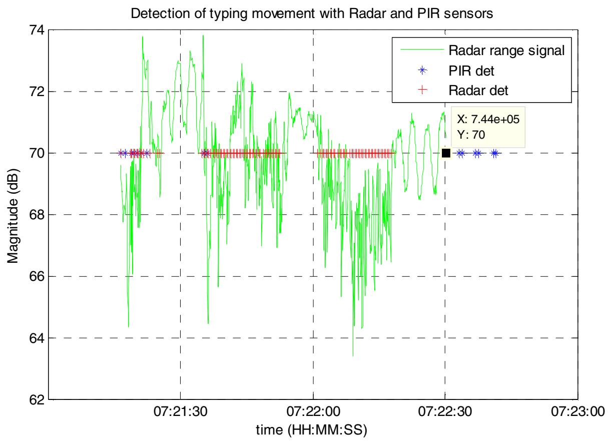

Fig. 6. Comparison of radar and PIR detection when typing and sitting still.

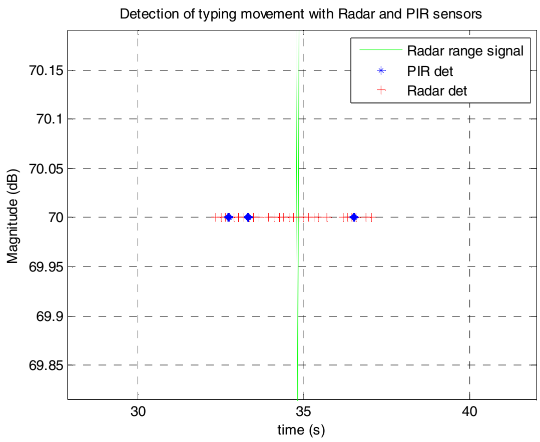

Fig. 7. Detail of radar and PIR detection while typing.

During a second measurement, next to typing and sitting still, arms movements are added up. Results are shown in Fig. 8. In this case both sensors detect arm movements.

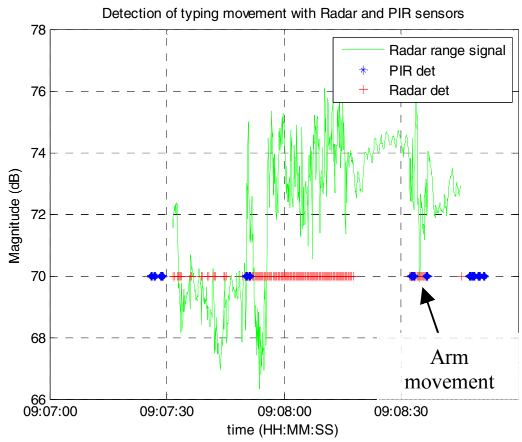

Fig. 8. Detection of typing, breathing and arm movements.

Additional measurements with an empty room or with a small office plant with moving branches have been carried out, in order to check false alarm rates of the systems. When the room is empty, both systems do not detect any presence. In the case of the plant, an extreme situation with the plant on the boresight of the radar and a fan switched on has been considered. A periodicity of the signal can be observed in Fig. 9. When the fan is set to a maximum speed, the movement of the leaves is detected by the radar, causing false positives.

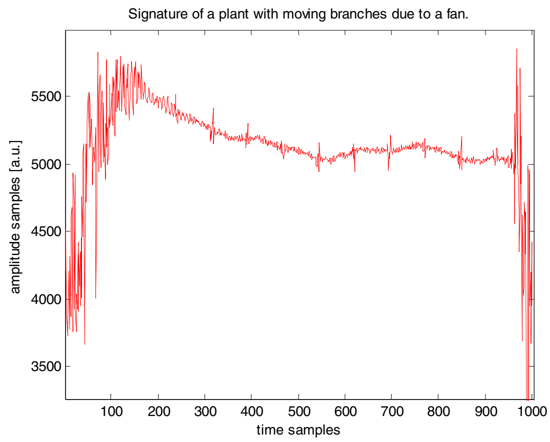

Fig. 9. Signature of a plant with moving branches due to a fan.

It is important to point out that the latter measurement does not correspond to a real situation, in which the plant is usually at the side of a desk, i.e. next to a window and the leaves' movements are caused by the heating.

VII. Conclusion

In this paper measurements with a novel radar on a chip for real time detection of small movements, i.e. typing were presented. A comparison of detection performances with a PIR sensor has taken place. The first results show that the radar can detect a small motion of the fingers (along the radial direction) while typing, while the PIR sensor can only detect larger tangential movements. The proposed algorithm is very sensitive and computationally not very demanding, making it suitable to run directly in the microcontroller. The radar dimensions and power consumption fulfill the requirements for intelligent LED lighting systems, making it a suitable candidate for motion detection.

References

[1] www.enlight-project.eu.

[2] E.M. Suijker et al., "Low cost low power 24 GHz FMCW radar trasceiver for indoor presence detection", 44th European Microwave Conference (EuMC) 2014, in press.

[3] E.B. Soyer, "Pyroelectric Infrared (PIR) Sensor Based Event Detection", MSc Thesis, July 2009.

[4] http://www3.panasonic.biz/ac/e/search_num/index.jsp?c=detail&part_no =EKMC1601111.