Exploring the limits of a low-cost FMCW radar

Degree programme: BSc in Electrical Engineering and Information Technology
Specialisation: Embedded Systems
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Frequency Modulated Continuous Wave (FMCW) radars can achieve micrometer-level precision, but typically require a high-performance microcontroller. In contrast, this project demonstrates a low-cost FMCW radar system, implementing essential digital signal processing (DSP) for distance measurements and exploring fundamental range resolution and range limits.

Context and goals

A low-cost radar prototype was developed in a previous bachelor's thesis using a Silicon Radar chip operating between 122 GHz and 123 GHz as well as a Texas Instruments Hercules microcontroller featuring a 32-bit central processing unit (CPU), floating-point unit, and dual analog-to-digital converters (ADCs). The goal of this project was to implement a software for FMCW operation as well as to investigate range limits and detection accuracy between 1 m and 2 m.

Concept and implementation

In a FMCW radar, the transmitted signal is delayed upon reflection, producing a frequency difference between transmitted and received signals that increases with range. Mixing these signals generates a beat frequency in the kHz range, which can be used to calculate distances. The radar uses a sawtooth waveform with configurable bandwidth, while slope (chirp) duration is determined by the sampling frequency and the number of samples plus a margin. The ADC sampling is synchronized with the chirp. ADC sampling captures 1024 samples per chirp, and a frame consists of 16 chirps for distance measurement, while velocity is sampled without frequency modulation for better results by exploiting the Doppler effect. Signal processing on the distance data (Fig. 1) includes fast Fourier transforms (FFTs), subtraction of a baseline measurement to enhance object detection, peak detection, and frequency-to-distance conversion.

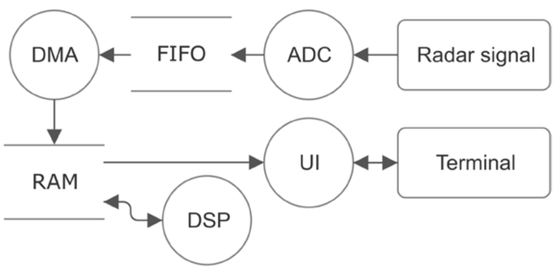

Fig. 1: The data flow diagram shows part of the software architecture and how the different modules work together.

Results

The project achieved all mandatory and high priority optional goals. The implemented software supports customizable radar parameters, including bandwidth, sample count, frame size, detection thresholds, and averaging settings. A serial terminal interface supports data sharing through human-readable formats or a defined telegram format, along with raw data dumps, debug values, and runtime parameter configuration. The test setup (Fig. 2) showed that the maximum range is 7 m at 1 GHz or 2.5 GHz bandwidth. Distance resolution improved with increasing bandwidth, achieving the expected 31.5 cm at 1 GHz, 12.6 cm at 2.5 GHz, and 4.4 cm at 7 GHz. The detection of humans and water surfaces were also confirmed. In addition to the distance, object velocity and direction were demonstrated, although not fully validated.

Conclusion and future work

The radar's distance detection limits and resolutions matched theoretical expectations. The software is expandable with future optimizations, including testing radar lenses, enhancing DSP with adaptive thresholds for better detection, and faster processing with smaller sample size and lower sample rate. Advanced DSP techniques may further increase precision and multi-target detection, pushing the microcontroller to its limits.

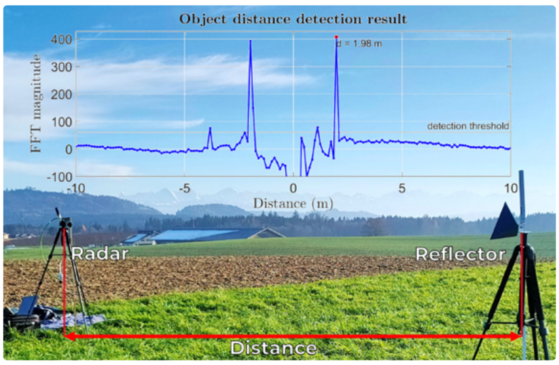

Fig. 2: The test setup including the radar and a corner reflector. Above, example data of a processed object distance.

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