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MM-Wave Imaging Radar

I. Introduction

Camera systems are in widespread use as sensors that provide information about the surrounding environment. Whilst the human brain can easily interpret the images that they create, it is a difficult matter for software algorithms to do so in some scenarios. For example, if a camera is viewing an urban scene and the objective is to count the number of people passing through a portal, a human operator could do that easily but for a limited time period. A machine of reasonable cost and size cannot, with the current state of the art, adequately perform this task.

Another example is the case where an autonomous vehicle needs to build an internal map of its surroundings in order to plan its activity. The required information is there in camera images (especially if they are stereoscopic) and a human could quickly and easily sketch the world that they reveal. A machine solution to this is nevertheless still highly challenging.

The fundamental reason why machine interpretation of camera images is hard is that it relies on a deep understanding of objects that might compose the world; colours, shapes, sizes, features, textures, views from different perspectives etc. Research in this area is vibrant of course but a solution that can solve this in a package that is of sensible size and cost still seems a long way off.

High resolution radar is known to be an alternative to or an augmentation of a camera sensor. The output it produces lacks the exquisite detail that a camera creates but it much more readily reflects the geometry of the world it views. A radar that scans in both azimuth and elevation also measures the range to any target it detects so a direct, 3-dimensional estimate of its location is provided. It is also possible for a radar to directly determine the motion of a target (through Doppler) and, for example, use this to only detect targets that are moving.

Radar is widely used in the automotive industry to determine the relative position and motion of vehicles on the road. This direct information can then be used to operate cruise control or trigger the deployment of air-bags before an impact. With a few exceptions, these radars do not scan they stare with fixed beams ahead of or to the side of the vehicle. In that sense they are rather unsophisticated and highly tuned for cost and application. More advanced scanning radar is being actively pursued in research directed at driverless vehicles. For example, vehicles undertaking the DARPA challenge [1] have for a long time used scanning high resolution radar to help ascertain the local terrain and obstacles. Similarly, military autonomous vehicles and large commercial vehicles are making use of such methods [2].

Whilst these systems have traditionally made use of costly, bulky, high performance, high frequency RF circuits, the adoption of SiGe device integration is seeing device vendors coming forward with many potential radar solutions in single-chip form. The general point to keep in mind is these single-chip solutions cannot, as of now, by themselves, provide the fine-grain scan needed for most applications. A bridge is needed between these very low cost devices and the expensive solutions that currently exist with a scanning capability.

II. Applications

A. Autonomous vehicles

It has already been said that the radar sensor is a good choice for autonomous vehicles because it directly provides information that is useful in planning routes and reacting to events. As far as we know, all current solutions are physically large, expensive and have high power consumption. This precludes their use on many smaller platforms, particularly small UAVs which have a ‘sense and avoid’ challenge that the radar would be especially well adapted for.

For the UAV, the sensor would need to detect objects that are in the flight path, localize them in 3D space and be able to plan a route that avoids catastrophe. The radar range corresponds to the time and distance the UAV system needs to detect and maneuver; perhaps 50m for a medium-sized platform.

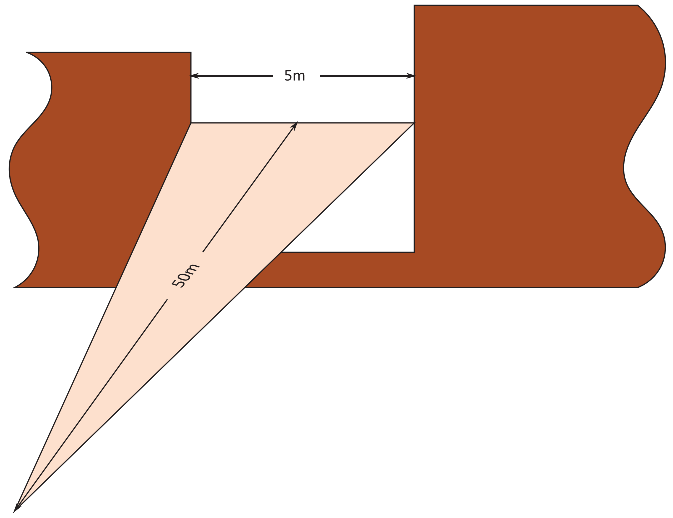
Many different scenarios can be foreseen that will demand target resolution in the radar. For example, it would need to distinguish between the following two cases: Firstly, a solid wall ahead that forms an obstacle. Secondly a wall with a gap in it than can be safely negotiated. The geometry of this, shown below, requires an azimuth resolution of approximately 3^{O} to enable the UAV to determine a safe path. The main consideration in determining elevation resolution is that the sensor must be able to distinguish between elevated obstacles and the ground. It could be argued that elevation beam-width could be somewhat larger than the azimuth for this reason but for now we assume a symmetrical antenna where beam-widths in both axes are similar.

IV. Next Steps

At Plextek we plan to engineer the mm-wave prototype radar so that it incorporates a fast mechanical scan and the supporting electronics to achieve real-time data capture and processing. It will also get us closer to the required size, weight, power and cost. This platform will then be used to explore the effectiveness of the technology in the different application areas discussed in this paper.

V. References

1. Darpa Challenge https://en.wikipedia.org/wiki/DARPA_Grand_Challenge
2. Navtech Radar http://www.navtechradar.com/
3. Desert Hawk www.lockheedmartin.co.uk/content/dam/.../Desert-Hawk-brochure.pdf
4. Ultrahaptics http://ultrahaptics.com/
5. Traffic radar http://www.wavetronix.com/en-GB/products/smartsensor/technology



Requirements

Range	50m
Azimuth beam-width	4^{O}
Elevation beam-width	4^{O}
Range resolution	100mm
Antenna aperture size	90x90mm
Scan time	1s
Weight	100g
Size	100x100x200mm
Power consumption	10W.

B. Human Computer Interface

Conventional ways of interacting with a computer have limitations

1. If the computing device is too small to carry a keyboard, a touch screen, etc.

2. When rich information is needed such as the user's location, posture etc.

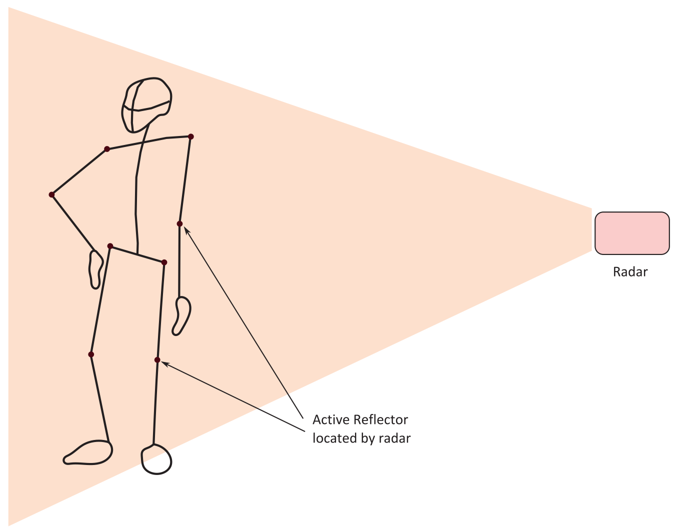
A lot of work is being done to address these shortcomings under the general heading of gesture recognition. UK startup Ultrahaptics [4] has combined ultrasonic gesture recognition (a fairly well established method) with a haptic feedback based on interaction of ultrasonic waves. For very short range applications ultrasonics seems to be the method of choice.

Longer range applications which are difficult to meet with ultrasonic methods include:

1. Virtual reality HCI

2. Measurement of body kinematics for example in sports science or the film industry.

A radar of the kind described so far would be able to pick people out of a cluttered scene effectively, certainly it is likely to be more efficient at this task than a camera. However, it is not going to be possible to obtain the detail that these applications hope for (the position of an arm or a head). We propose the use of active radar reflectors attached to these body points to allow the radar to resolve these particular points in space from all other target returns. This concept is shown below. The active reflector can be small (10 – 20mm in diameter) and only requires a small power source to modulate the scattered signal (it does not generate any RF itself).



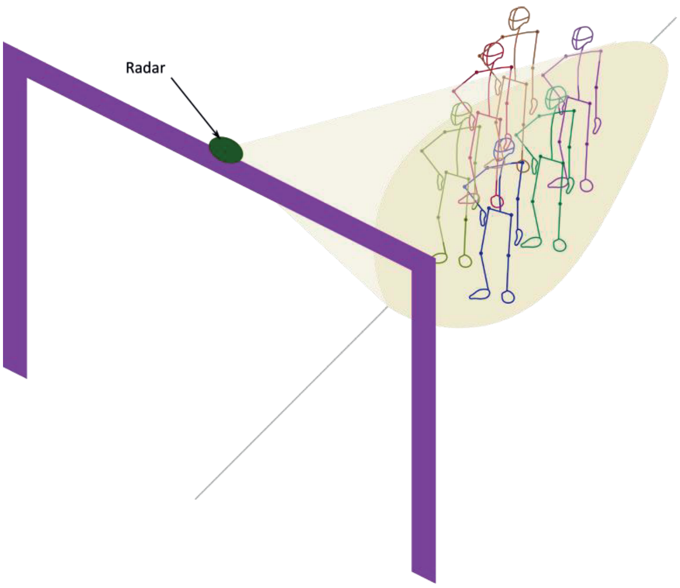
Requirements

Range	20m
Azimuth beam-width	2^{O}
Elevation beam-width	2^{O}
Range resolution	20mm
Antenna aperture size	180x180mm
Scan time	1s

C. Transport Systems

Products using fixed radar beams to detect vehicles are commonplace [5]. Typically they are either an adaptation of standard automotive radar (77 GHz) or are custom designs operating at a much lower frequency. In either case they do not scan and therefore are limited to situations where one knows where the target will pass. Applications include assessing traffic flows of vehicles in cities.

A more difficult problem with plenty of commercial clout behind it is assessing traffic flows of people into transport systems. There is currently no good solution for this. The requirement is essentially to be able to accurately determine the number of people entering (or exiting) through a portal. This is complicated by clumps of people appearing to be a single 'target', people walking in different directions etc. Users would also be interested in determining exception cases (such as people running).



Requirements

Range	20m
Azimuth beam-width	4^{O}
Elevation beam-width	4^{O}
Range resolution	100mm
Antenna aperture size	90x90mm
Scan time	1s

D. Building security

This application is currently served by an array of PIR sensors to determine whether a room is occupied and CCTV cameras to gather high-level information. There may be a market for a sensor that is of similar cost and size to the PIR module but is able to autonomously say something more interesting than just "hello something is moving". This might include:

1. The number of people inside a room
2. The motion of those individuals (from which behaviour can be inferred)

The sensor would need to be low cost (probably) and this might mean, for example, that we dispense with the elevation scan leaving a radar that localises in azimuth and range. Probably this will provide enough detail (with high range resolution) to achieve the aims set out above.

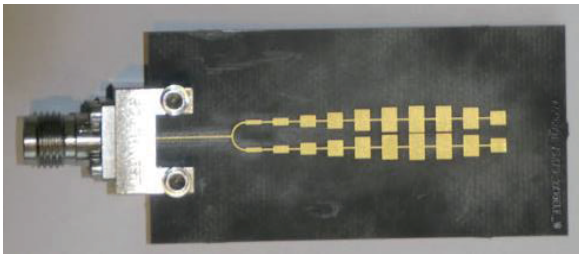
Requirements

Range	20m
Azimuth beam-width	4^{O}
Elevation beam-width	30^{O}
Range resolution	10mm
Antenna aperture size	90x10mm
Scan time	1s

III. Technical challenges

A. Scanning

One missing element is the ability to scan the radar in azimuth and (in some cases) elevation in a way that is low cost, power efficient and fast. Phased array solutions are promising for the future but we do not think that any currently achieve the resolution needed by these applications at feasible cost and power consumption. Frequency scanning is a technique that has been extensively developed by Plextek (for example in the Blighter radar). We have shown that it is feasible to translate this to mm-wave in a number of prototype antennas, an example of which can be seen below.



We have also been experimenting with extremely efficient mechanical scanning mechanisms that rely on resonance to achieve a high scan rate using only a meagre amount of power.

B. Object rendering

Most of the applications (with the exception of systems using active reflectors probably) are not very interested in raw radar detections. They want to know what objects are out there in the world, where they are and how they are moving. There is a step needed to spatially cluster individual radar detections into objects. This is not a trivial problem. To explore this Plextek has built a scanning radar with a $3x3^{O}$ aperture and a 250mm range resolution. We have used this prototype to investigate the 'view of the world' provided by this sensor and the kind of processing that can be used to make this accessible to human and machine interpretation. The pictures on the next page show some early results of this work.

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