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PROJECT SOLI: Gesture Recognition in the Radio-Frequency Spectrum.

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Abstract

This paper presents Project Soli, a new category of gesture sensors based on physical principles of millimeter-wave RF radiation that were not previously explored in interactive applications. It's a new, robust, high-resolution, low-power, miniature gesture sensing technology for human-computer interaction. Soli is a new technology that uses radar to enable new types of touch less interactions. An RF silicon sensor uniquely designed for fine hand gesture interaction, based on new principles of radar hardware design and signal processing. This technology considers the design of a human gesture recognition system based on pattern recognition of signatures from a portable smart radar sensor. The movements of gestures from a human can be captured using a radar sensor, and by detection of theses gestures, some special task on a device can be done. The project is under research by Google ATAP, and it is termed as Project Soli. In this technology, a Radar sensor along with a capturing system is made into a small chip and this chip can be connected to any device like Computer, Smartphone etc. The different functions in these devices like Call, Volume control, Zoom etc. can be done using specific gesture without having to touch or use another interaction method. We describe a new approach to developing a radar-based sensor optimized for human-computer interaction, building the sensor architecture from the ground up with the inclusion of radar design principles, high temporal resolution gesture tracking, a hardware abstraction layer (HAL), a solidstate radar chip and system architecture, interaction models and gesture vocabularies, and gesture recognition. We demonstrate that Soli can be used for robust gesture recognition and can track gestures with sub-millimetre accuracy, running at over 10,000 frames per second on embedded hardware. The proposed model runs on commodity hardware at 140Hz (CPU only).

Index Terms: *Interaction, Gesture recognition, Radio frequency, Radar sensing, Google ATAP.*

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1. INTRODUCTION

Soli is the first millimeter-wave radar system designed end-to-end for ubiquitous and intuitive fine gesture interaction. It is a new, robust, high-resolution, lowpower, miniature gesture sensing technology for interactive computer graphics based on millimeter-wave radar. Radar operates on the principle of reflection and detection of radio frequency electromagnetic waves [Skolnik 1962]. The RF spectrum has several highly attractive properties as a sensing modality for interactive systems and applications: the sensors do not depend on lighting, noise or Atmospheric conditions are extreamly fast and highly precise; and can work through materials, which allows them to be easily embedded into devices and environments.

When implemented at millimeter-wave RF frequencies, the entire sensor can be designed as a compact solid-state semiconductor device: a radar chip that is a miniature, low-power device having no moving parts and can be manufactured inexpensively at scale. The resulting Soli sensor delivers the promise of truly ubiquitous gesture interaction across a very broad range of applications, including but not limited to virtual reality (VR), wearables and smart garments, Internet of Things (IoT) and game controllers, as well as more traditional devices such as mobile phones, tablets and laptops.

Millimeter-wave radar has the potential to serve as basis for mobile gesture recognition by overcoming many issues in vision based and low-frequency RF sensing. However, it

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brings a number of new challenges for HCI and gesture recognition research: sensing in the electro-magnetic spectrum eschews spatial information for temporal resolution. Capturing a superposition of reflected energy from multiple parts of the hand such as the palm or fingertips, the signal is therefore not directly suitable to reconstruct the spatial structure or the shape of objects in front of the sensor. However, the signal does capture motion even of very small magnitude and it is possible to discriminate very subtle and precise hand motions and gestures. Embracing this challenge we propose a novel deep learning based gesture recognition approach specifically designed for the recognition of dynamic gestures with millimeter wavelength RF signals.

In this work, we present the first end-to-end radar sensing system specifically designed for tracking and recognizing fine hand gestures. Our work builds upon a large existing body of knowledge in the radar domain and, for the first time, explores the comprehensive design principles, implementation, and optimization of these tools for scalable gesture sensing within the constraints and requirements of modern HCI. We show that ubiquitous and intuitive gesture interaction is made possible through tailored, interdependent design of the entire sensor architecture.

1.1 Google ATAP

Google's Advanced Technology and Projects group (ATAP) is a skunk works team and inhouse technology incubator, created by former DARPA director Regina Dugan. ATAP is similar to X, but works on shorter projects, granting project leaders only two years in which to move a project from concept to proven product. According to Dugan, the ideal ATAP project combines technology and science, requires a certain amount of novel research, and creates a marketable product within the two-year time frame. Historically, the ATAP team was born at Motorola and kept when Google sold Motorola to Lenovo; for this reason, ATAP ideas have tended to involve mobile hardware technology.

1.2 Project soli

Project Soli is a new way of touch less interactions one where the human hand becomes a natural, intuitive interface for our devices. It is a sensing technology that uses miniature radar to detect for motion tracking of the human hand. The founder of Project Soli is Ivan Poupyrev. Project Soli was revealed during Google I/O 2015 on May 29, 2015. Google and Infineon are working together on project Soli. Infineon will provide hardware and application support while Google will provide software documentation and algorithms. The RADAR technology is used in project Soli.

2. RADAR

Radar is an acronym for RAdio Detecting And Ranging. The name itself suggests that the radars are used to detect the presence of object and determine its range, i.e., distance and bearing, using radio frequency waves.

-Fig-1: Radar

2.1 Soli Radar System

Historically, radar system design was driven by applications such as detecting, locating, and identifying aircraft, ships, and other rigid targets. These applications are significantly different from tracking and recognizing complex, dynamic, deforming hand shapes and fine motions at very close range. The fundamental principles of radar sensing are straightforward (see Figure 2). A modulated electromagnetic wave is emitted toward a moving or static target that scatters the transmitted radiation, with some portion of energy redirected back toward the radar where it is intercepted by the receiving antenna. The time delay, phase or frequency shift, and amplitude attenuation capture rich information about the target's properties, such as distance, velocity, size, shape, surface smoothness, material, and orientation, among others. Thus these properties may be extracted and estimated by appropriately processing the received signal.

Radar uses electromagnetic energy pulses in the same way. The radio-frequency (RF) energy is transmitted to and reflected from the reflecting object. A small portion of the reflected energy returns to the radar set. This returned energy is called an ECHO, just as it is in sound terminology. Radar sets use the echo to determine the direction and distance of the reflecting object.

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Fig-2: The fundamental principles of radar sensing are based on transmission and reflection of RF waves.

2.2 Gesture Recognition

Gesture interactions for Soli is build on the strengths of the radar sensor while recognizing human ergonomic and cognitive needs. Gesture recognition with camera-based systems typically interprets image and depth data to build and track a skeletal model of the human body or hand. Instead of static shapes, the key to Soli interaction is motion, range and velocity, where the sensor can accurately detect and track components of complex motions caused by a user hand moving and gesturing within sensing field. Soli technology therefore focus on using gestures with a clear motion component, that is refered to as Action Gestures, rather than gestures that are expressed as static hand shapes, or Sign Gestures. Following is the list of Action Gestures processed by Soli (Refer to Fig-3 a,b) –

a) Pinch Index
b) Pinch Pinky
c) Finger Slide
d) Finger Rub
e) Slow Swipe
f) Fast Swipe
g) Push
h) Pull
i) Palm Tilt
j) Circle
k) Palm Hold

Fig-3(a)

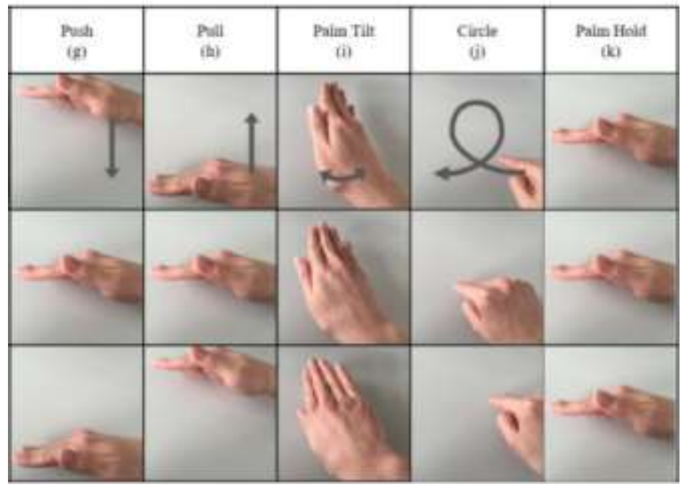

Fig-3(b)

The fundamental approach to gesture recognition with Soli is to exploit the temporal accuracy of radar. Therefore, it recognize gestures directly from temporal variations in the received radar signal by extracting and recognizing motion signatures in the Soli transformations. This is contrary to many existing gesture sensing approaches that are primarily spatial and explicitly estimate a hand pose or skeletal model prior to recognizing gestures. In addition to exploiting the temporal accuracy of radar, Soli's gesture recognition was designed to (i) maintain the high through put of the sensor to minimize latency;(ii) exploit advantages of using multiple antennas to maximize SNR and improve recognition accuracy; (iii) provide both discrete and continuous predictions3; (iv) be computationally efficient to work on miniature, low-power devices, e.g. smart watches.

3. HARDWARE

The Soli sensor is a solid-state millimeter-wave radar for mobile gesture recognition. Classic radar approaches rely on high spatial resolution to discern several rigidly moving targets (e.g., planes). In contrast Soli uses a sensing approach that prioritizes high temporal resolution to detect subtle, non rigid motion. Soli utilizes a single broad antenna beam to illuminate the entire hand as modulated pulses are transmitted at very high repetition rates (between 1-10 kHz).

3.1 Soli sensor

Soli's radar sensor is a marvel in many respects. For one thing, it solves a long-lived issue when it comes to gesture-recognition technology. Previous forays into the topic yielded almost-answers such as stereo cameras (which have difficulty understanding the overlap of fingers, e.g.) and capacitive touch sensing (which struggles to interpret motion in a 3D context).Google ATAP's answer is radar. Radar is capable of interpreting objects' position and motion even through other objects, making it perfect for developing a sensor that can be embedded in different kinds of devices like smartphones. The difficulty was that radar hardware is too large for wearable applications. Way too large. Even the scaled-down early prototypes ATAP developed were about the size of a briefcase. However, after several iterations, the current model is only 8mm x 10mm: smaller than a dime. And that's including the antenna array. This radar tech went from the size of a briefcase to the size of a dime in a span of ten months. The Soli sensor is a fully integrated, low-power radar operating at 60-GHz.

The Soli embedded system, developed in partnership with Infineon, is also a large stride forward. For comparison, evaluating normal radar information often requires the use of a supercomputer.

3.2 Soli Chip and System Architecture

Through the course of our hardware development, we iterated through several implementations of Soli hardware architecture, progressively shrinking the system from a desktop sized radar box down to a single chip. Our early FMCW radar prototype (Figure 4, top left) was a custom 57-64 GHz radar built out of discrete components using Infineon's BGT60 backhaul communication IC with multiple narrow-beam horn antennas. In parallel, we developed ultra wide band (UWB) 3-10 GHz impulse radar prototypes based on Novelda's XeThru NVA620x IC [Novelda] (Figure 4, top right), including the design of multiple incorporated coherent receive antennas, such as a hybrid Archimedean Power Spiral. It quickly became apparent that the form factors and power requirements of these prototypes could not support our ultimate vision of the radar gesture sensor integrated into mobile and wearable devices. Furthermore, in the case of the UWB radar, the centimetre scale wavelength did not allow for sufficient phase sensitivity required for fine gesture interaction, and the size of the antennas could not be reduced any further while maintaining wide bandwidth and sufficient gain.

Recent advancements in semiconductor technology made it possible for us to dramatically miniaturize the radar hardware from our initial prototypes. The increased availability of new CMOS, BiCMOS, and SiGe process technologies with ever-shrinking technology nodes enables high-frequency RF circuitry (>30 GHz) necessary for millimeter-wave radar. Furthermore, modern silicon die packaging technologies allow the placement of antennas directly on the package, either by stacking them vertically on top of the silicon die or by placing then horizontally on the same plane. These technologies allow for complete integration of the sensing radar, including antennas and computation, into a single chip.

Fig-4: Top: Early prototypes of Soli FMCW and impulse radars. Bottom: Soli radar 60 GHz chips with antennas-in-package (AiP).

4. SOLI ALPHA DEVELOPMENT KIT

Project Soli is Google's Post-Touch experiment and its Alpha Development Kit was released by Google in October of 2015. It first shipped a developer kit to about 60 developers last year. The team said it was encouraged by how those developers used the sensor; they built object recognition tools, musical instruments and more. The early kit, though, was really only usable in a controlled environment. It used too much power and while the sensor was small, it did need a fully powered desktop or laptop to run it.

5. APPLICATIONS

The Project Soli has numerous applications in various technology demanding fields. Due to the small form factor, low power consumption and low cost of RF based gesture sensors, we can envision use of this technology in wearable and mobile interaction, smart appliances and Internet of Things, mobile VR and AR systems, interactive robots and drones, game controls, smart objects and garments, massively interactive physical environments, as well as novel techniques for scanning and imaging physical environment, way finding, accessibility and security, mobile spectroscopy, and many other exciting applications.

Soli can be extremely useful in the range sensing of fine and fluid gestures based on the Virtual Tools. It envisions that the same vocabulary of simple touchless gestures can control a broad range of devices across multiple application categories. For example, the same gesture that allows one to navigate a map on a smart watch can be used to control music on a radio, manipulate graphics on a tablet, or simply set an alarm clock.

The soli chip can be used in the gaming interfaces. It can be embedded in the computer devices and gaming devices and then you play games by providing input through gestures to machines. It will amazingly change the gaming experience.
Smart phones and smart watches can also make efficient and dynamic use of the Soli chip. The gestures like scrolling, clicking, swiping, sliding, etc can be performed without any physical interface just by the hand gestures; it will surely take the gadget's experience to the new highs.

The Soli chip can help in healthcare too. As the use of electronic information in healthcare has resulted in a similar expansion of the quantity of computers, tablets and dashboards used in the hospital environment, and it is not unusual to have thousands of such devices in a medium-sized acute care hospital (300-500 beds). This poses a very real challenge for infection control professionals, as many of the surfaces are used constantly, but can suffer damage from the strong chemicals used to clean them. Incorporating Project Soli-type chips would allow users to control devices without touching them, reducing the risk of spreading infections. This could mean that not only would there be fewer germs present, but also that surfaces could be constructed with more durable materials if they do not have to recognize touch inputs.

6. ADVANTAGES

- Replace all kinds of buttons and switches and make the devices operable remotely.
- Allows controlling gadgets with gestures.
- Allows free hand typing.
- Good accuracy over control.
- Need not to carry gadgets while using them.
- Virtual controlling of devices.
- Can be used in cell phones and in other devices.
- Used to operate radio.
- To adjust time.

7. DISADVANTAGES

- It has a very small radar range.
- Multiple gestures could not be possible.
- Since this technology is fairly new to the industry it will be very expensive but as time goes on its price will eventually reduce.
- Most of the gestures may require training before use this may get very time consuming.

8. CONCLUSION

Project Soli is a new technology that uses radars to enable new type of touchless interactions. This technology considers the design of a human gesture recognition system based on pattern recognition of signatures from a portable smart radar sensor one of the big problems with wearable devices right now is inputs - there's no simple way to control these devices. Therefore gestures will be used by individuals to carry out certain functions with electronic machines. In this technology, a Radar sensor along with a capturing system is made into a small chip and this chip can be connected to any device like computer, Smartphone etc. The different functions in these devices like call, volume control, zoom etc. can be done using specific gesture without having to touch or use another interaction method

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