RFLOW: User Interaction Beyond Walls

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ABSTRACT

Current user-interaction with optical gesture tracking technologies suffer from occlusions, limiting the functionality to direct line-of-sight. We introduce RFlow, a compact, medium-range interface based on Radio Frequency (RF) that enables camera-free tracking of the position of a moving hand through drywall and other occluders. Our system uses Time of Flight (TOF) RF sensors and speed-based segmentation to localize the hand of a single user with 5cm accuracy (as measured to the closest ground-truth point), enabling an interface which is not restricted to a training set.

Author Keywords

Radio-frequency; Hand-tracking; 3D; Through-wall

ACM Classification Keywords

H.5.m. Information interfaces and presentation.

INTRODUCTION

There is a growing demand for context aware, wireless, human-machine interfaces. Optical techniques are high in resolution, but are limited by occluders such as walls. Magnetic tracking works through occluders, however is sensitive to static-clutter and requires instrumentation of the user. Radio Frequency techniques enable contact-less tracking of features.

Recently the field of RF based interactive systems has exploded with innovation. Researchers have used various RF signals to perform non-contact un-instrumented interaction. Often this work centers around classifying a set of predefined gestures, however this limits the vocabulary of interaction and requires large training sets [4,5,7,8]. Other work has focused on localization and has produced results in tracking bodies and course arm-motions [1-4]. We demonstrate a system which extends these results in order

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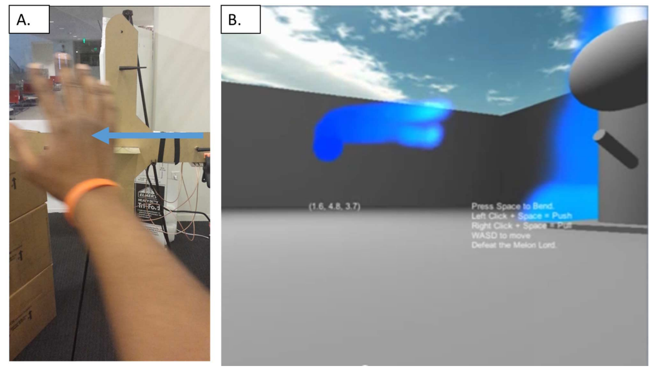

Figure 1: A live demo of a user moving their hand in front of the system. A) A user moves their hand in front of the system to control the position of an orb in B). Note that the wristband plays no role in the tracking.

to track smaller objects, such as a hand, with 5cm accuracy.

We rely on measuring the TOF between our transmitter, reflectors in the scene, and 4 antennas to localize objects. The accuracy of our localization system is linked to time resolution (bandwidth), signal to noise ratio, and aperture size (distance between antennas). While other systems broadcast high power into smaller bandwidth FCC gaps (2GHz), our system utilizes low-power transmitters across a wide gap (6GHz). This increases the time accuracy of our system while limiting the range of operation to <2 meters in front of the device. This enables our system to localize with greater accuracy and track reflective objects, such as a user's hand, water-based objects, and metallic objects.

IMPLEMENTATION

Our setup consists of an ultra-wideband transceiver which transmits a pulse of 10GHz bandwidth (100ps in duration). This pulse is repeated while the transceiver uses Continuous Time Binary Value (CTBV) architecture [6] to sample in the time-domain at 36GHz and thus measure the time of flight of the radar pulse. The transceiver is multiplexed between four antennas and the user's hand is localized.

SEGMENTATION

The system is designed to only track a single moving hand raised towards the interface. We implement a segmentation algorithm to separate the user's hand response from that of

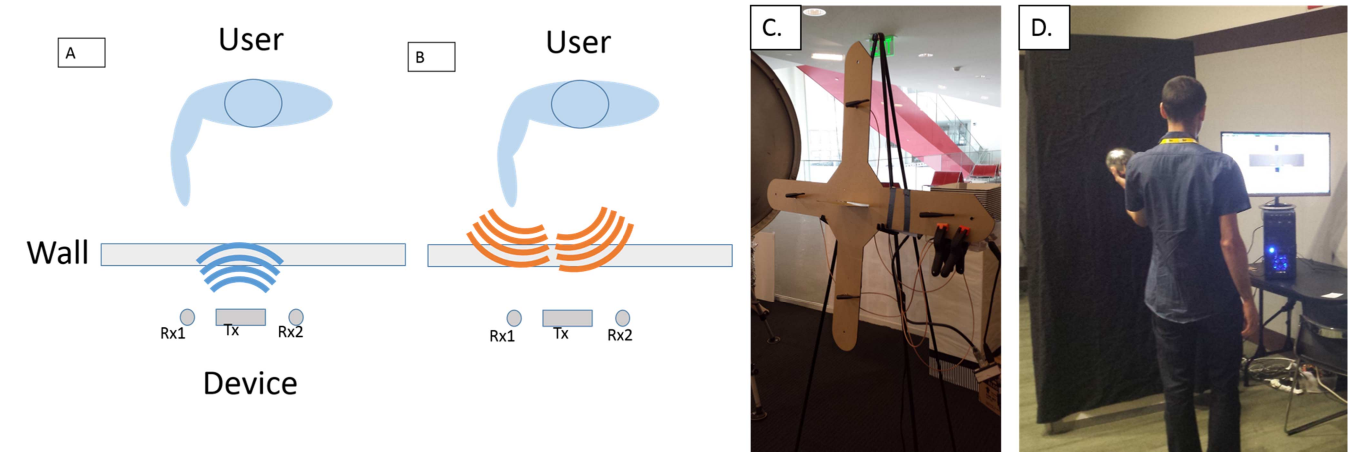

Figure 2: The system can operate behind walls and obstructions. A) The system transmits through the wall. In B), the signal reflects off of a user hand and returns to the system. In C), one can see a photo of the system which is light and compact. In D) a user moves a metal sphere in front of a wall with the system positioned behind the wall, demonstrating the capability to track other objects besides hands.

the body and other reflectors. First, static objects in the scene are cancelled, thus leaving the user's hand and body response. In order to distinguish between these, the system tracks the faster of the two moving objects, with the prior that the hand is usually closer to the system than the body. The result of the measurements is placed through a Kalman filter, leading to smoother results at the cost of signal delay.

EVALUATION

In order to evaluate the accuracy of the system, a user moved their hand along a predifined track while the system made continuous measurements of the user's hand location. We exploited the transparent nature of styrofoam to create a predefined pattern (circle) the user moved their hand along. Accuracy was measured as the closest distance between a measured point and a ground truth point and is shown in figure 3. The mean error is <5cm between the ground-truth measurements and the system's measurements. The system is accurate while tracking a single target in front of the system, however there are interesting cases for future work, such as multi-user, multi-hand, and objects with complicated shapes which can appear stealth at particular orientations.

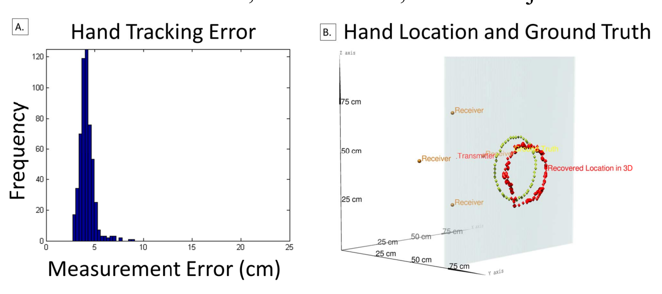

Figure 3: In A) a histogram shows the mean error in localizing the moving hand in front of the system. In B), the result of recovering the motion of a user hand in a circle. The user moved their hand along a predefined path printed onto RF-transparent styrofoam.

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