ROAD SURFACE QUALITY MEASUREMENT USING INEXPENSIVE RADAR

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Abstract—The near surface dielectric characteristics of pavement can indicate the overall health of roadways and bridge decks. By performing simple and fast reflectometry measurements of the near surface, it may be possible to efficiently monitor large amount of critical civil infrastructure, and provide early alerts of the initial stages of damage. We demonstrate the variation with moisture content of surface reflected waves using a commercial-off-the-shelf 24 GHz FMCW radar. Initial experiments show that detectable amounts of water is absorbed in asphalt and concrete. The amount of absorbed water increases with micro- and macro-cracking, and this measurement will correlate with quantifiable changes in the observed return signal.

Keywords: Radar, Reflectometry, Subsurface Sensing, Infrastructure Health Monitoring

INTRODUCTION

The problem of road and bridge deck deterioration is pervasive throughout the world, with an estimated repair cost of $1.6 Trillion in the U.S. alone. Repairs are time consuming and costly, especially when traffic is impeded as lanes are shut down for repairs. Identifying roadway damage early, before large portions of the pavement are affected and actual hazards result, can save considerable resources. In an effort to pervasively and automatically monitor roads, the Versatile On-board Traffic Embedded Roaming Sensors (VOTERS) program has been established to sense infrastructure health using a suite of noncontact sensors mounted on private and commercial vehicles.

One of the sensors in the suite will be a reflectometer based on an inexpensive 24 GHz radar. Although the high frequency microwaves generated by this system will not be able to penetrate to the most desirable detection depths of 10-40 cm, their reflection from the roadway surface and near surface provide a measure of the concrete or asphalt dielectric constants. In particular, differential water absorption in the roadway medium due to pavement integrity may be measureable and could correlate to its health.

COMPUTATIONAL MODELING

A modeling effort has been undertaken to establish reflection/penetration characteristics of roadway material, and to determine the sensitivity of 24 GHz pavement near-surface sensing. A representative 2-dimensional geometry consisting of a 10 cm planar aperture source positioned 20 cm above a uniform concrete road surface was modeled using the Finite Difference Frequency Domain (FDFD) method [1, 2]. The magnitude of the total field resulting from single frequency computation is shown in Figure 1.

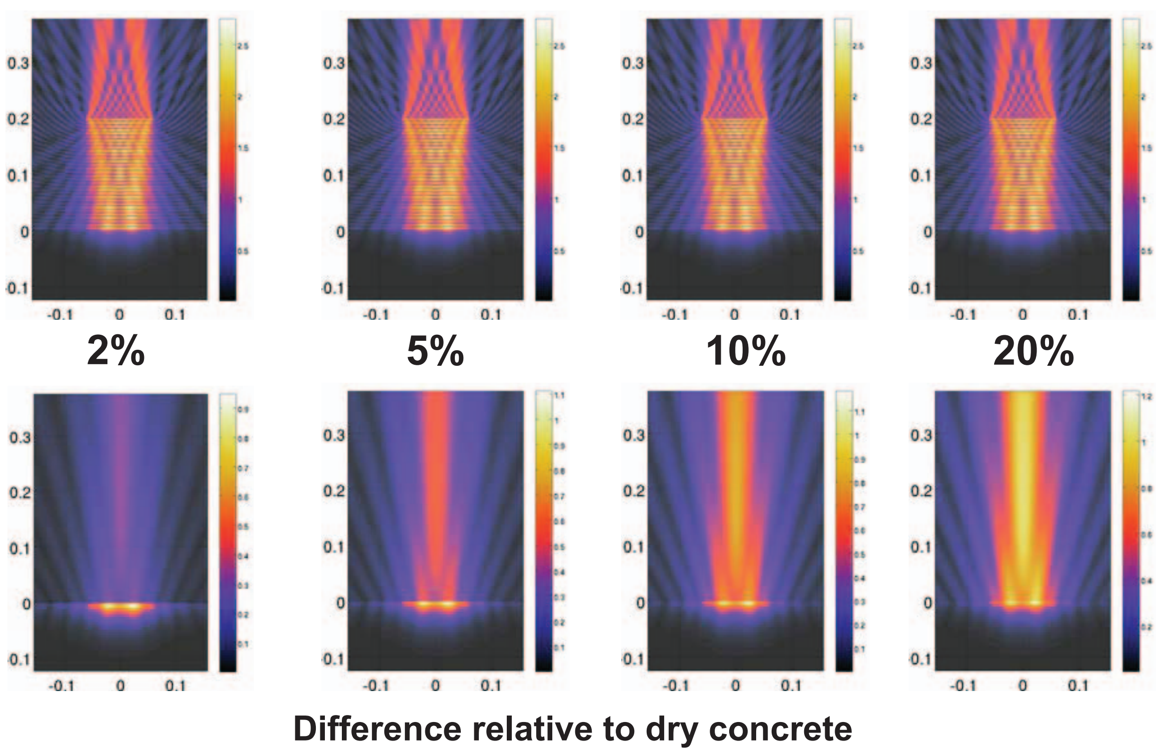

Figure 1: Total field (top row) and differential field relative to dry concrete (bottom row) for concrete half-spaces with various moisture concentrations (units in m).

The field penetrates as deep as 5 cm into the concrete half-space beginning at the zero point indicated on the vertical scale. In addition, the scattered field magnitude is shown for reflection from concrete with 2%, 5%, 10% and 20% volumetric water concentration that might be indicative of water infiltration into micro-cracks. The top row of images shows the total field, while the second row of plots shows and difference (relative to dry concrete) fields for these cases. The variations in scattered field are hard to see in the total field images, but the difference field images show scattered intensity that depends almost linearly on moisture content. These results indicates that 24 GHz narrowband radar has the potential to quantify moisture content, and by extension, the degree of near-surface micro-cracking.

ROAD SURFACE REFLECTIVITY MEASUREMENTSAT NORMAL INCIDENCE

A simple FMCW 24 GHz Walleye radar unit was built with separate transmit and receive horn antennas to test the reflection sensitivity. A 1 kHz sawtooth ramp was applied to the VCO to sweep 0.5 GHz in bandwidth. The reflected RF power was detected using an I/Q mixer input into a 100 MHz oscilloscope. Sample planar concrete and asphalt slabs were placed on a layer of microwave absorbing Eccosorb AN72 to eliminate spurious reflections from the target plane. Figure 2 shows the reflection responses from various

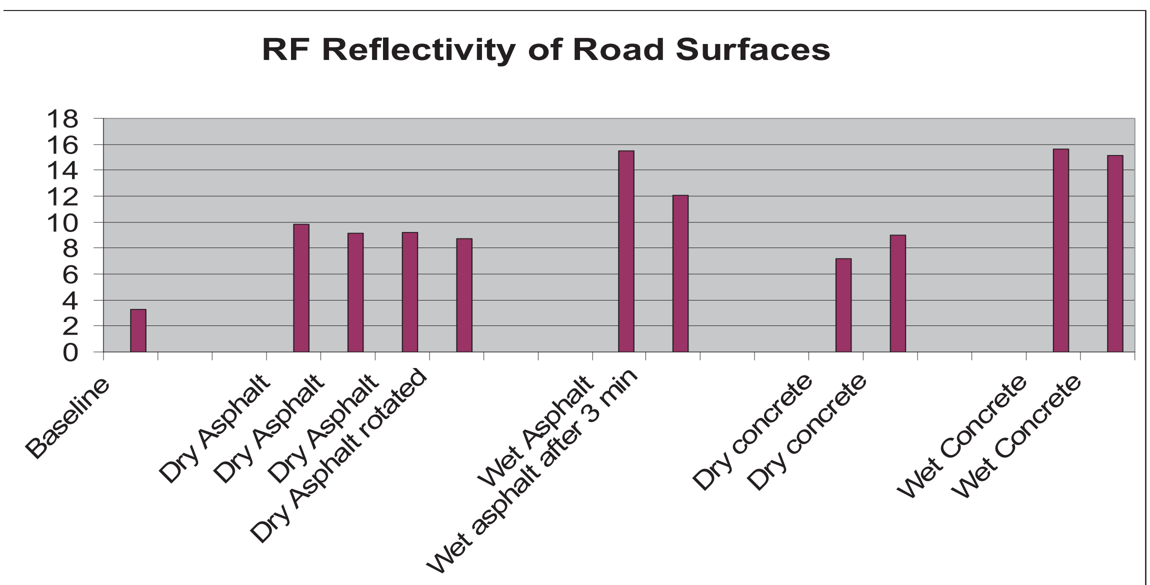

Figure 2: Measured 24 GHz reflection responses for various saturated and dry pavements

pavement test cases. Dry asphalt and dry concrete yield similar lower responses in the range of 7.2 to 9.2 on an unnormalized scale, while newly wetted asphalt and concrete have reflection responses in the range of 15.1 to 15.6, approximately 60% greater than the dry surfaces. When water was allowed to drain for three minutes, the reflection response reduces to 12.1, which is about 30% above the dry response.

CONCLUSIONS

The reflection characteristics of common planar roadway surfaces were modeled and experimentally measured with an inexpensive FMCW radar at 24 GHz under dry and wet conditions. Substantial scattering differences were both calculated and measured, indicating that high frequency commercial-off-the-shelf radar may offer an automatic, cost-effective means of monitoring moisture content, which in turn may potentially provide an early warning of precursors of more extensive pavement damage.

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