Effect of Electrode Polarization Impedance on Electroadhesion

Easa AliAbbasi[1], Ørjan Grøttem Martinsen[2], Fred-Johan Pettersen[2], and Cagatay Basdogan[1]

***Abstract*— We investigate the effect of electrode polarization (EP) impedance on electroadhesion (EA) between a human finger and a voltage-induced touchscreen. By conducting precise measurements of electrical impedances, we could ascertain the presence of EP impedance that operates in parallel with the impedance of the air gap between finger and touchscreen. Our findings indicate that the EP impedance plays a dominant role, particularly at low frequencies, thereby giving rise to the charge leakage phenomenon commonly observed in EA.**

I. Introduction

Since EA is governed by the accumulation and transfer of electrical charges [1], the electrical impedances of the touchscreen (TS), finger, and the air gap between them affect the movement behavior of those charges. Hence, their precise measurement can pave the way toward a deeper understanding of the physical mechanisms underlying EA. Since direct measurement of air gap impedance (Z_{Gap}) is not feasible, Shultz et al. [2] measured the electrical impedances of human skin (Z_{Skin}) and touchscreen (Z_{TS}) separately and subtracted them from the total sliding impedance (Z_{Total}); treating the remaining impedance (Z_R) as Z_{Gap}, which is considered in series with Z_{Skin} and Z_{TS}. However, our measurements demonstrate that Z_R is composed of Z_{Gap} and the EP impedance (Z_{EP}) in parallel [3]. Under EA, the ions in the finger skin tend to flow toward TS. Since TS has electronic charge carriers, the ions cannot pass the barrier between surfaces, which results in the formation of ionic double layers in those regions. Depending on the direction of the electric field, the ions gain or lose negative charges, which subsequently slows down the flow of current. This layer, in turn, causes the applied voltage to drop, thereby giving rise to a large and undesired Z_{EP}.

II. Materials and Methods

The measurement setup was composed of an impedance analyzer (MFIA 5 MHz, Zurich Instruments Inc.) to measure Z_{Skin}, Z_{TS}, and Z_{Total}, a TS (SCT3250, 3M Inc.), a force transducer (Nano17, ATI Inc.) placed beneath TS, and a data acquisition card (PCIe-6034E, National Instruments Inc.) to acquire and control the normal force at 1 ± 0.15 N during finger sliding.

[1]E. A. and C. B. are with the College of Engineering, Koc University, Istanbul 34450, Turkey. e-mails:ealiabbasi20@ku.edu.tr, cbasdogan@ku.edu.tr

[2]Ø. G. M. and F. J. P are with the Department of Physics, University of Oslo, Sem Sælands vei 24, 0371 Oslo, Norway and Department of Clinical and Biomedical Engineering, Oslo University Hospital, 0424 Oslo, Norway. e-mails: o.g.martinsen@fys.uio.no, frepet@ous-hf.no

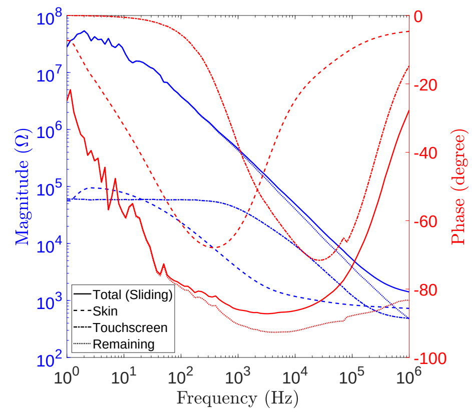

Fig. 1. Electrical impedances of Z_{Total}, Z_{Skin}, and Z_{TS}. The remaining impedance Z_R is obtained by subtracting Z_{Skin} and Z_{TS} from Z_{Total}. Z_R is made of Z_{Gap} and Z_{EP} in parallel.

III. Results and Discussion

Using one subject, we measured each impedance ten times per day and repeated the measurements on three consecutive days. The mean results are presented in "Fig. 1". The blue and red colored curves in the figure represent the impedance magnitudes and phases, respectively. $|Z_{Total}|$ (solid blue) is dominated by $|Z_R|$ (dotted blue), and $\angle Z_R$ (dotted red) shows a purely capacitive behavior at high frequencies indicating the dominant effect of Z_R on EA. Thus, Z_{Gap} can be modeled by a capacitance with air as its dielectric, and Z_{EP} with a capacitance representing an electrical double layer parallel to a leakage resistance. Our measurements show that Z_{EP} dominates Z_R at frequencies below ≈30 Hz, while its effect almost vanishes after that. Hence, the true impedance of the air gap and the magnitude of electrostatic forces should be calculated by considering the effect of Z_{EP}. With this knowledge, we plan to develop a comprehensive lumped-circuit model to estimate electrostatic forces between finger and TS under EA. Importantly, the proposed model will also facilitate the experimental estimation of the air gap thickness between finger and TS.

References

[1] E. AliAbbasi, M. A. Sormoli, and C. Basdogan, "Frequency-dependent behavior of electrostatic forces between human finger and touch screen under electroadhesion", *IEEE Transactions on Haptics*, vol. 15, no. 2, pp. 416–428, 2022.

[2] C. D. Shultz, M. Peshkin and J. E. Colgate, "On the electrical characterization of electroadhesive displays and the prominent interfacial gap impedance associated with sliding fingertips", *Proc. IEEE Haptics Symp.*, pp. 151-157, 2018.

[3] S. Grimnes and O. G. Martinsen, *Bioimpedance and bioelectricity basics*, Academic Press, 2015.