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An apparatus for sound, vibration and friction measurements of soft materials in aqueous environments

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A R T I C L E I N F O

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A B S T R A C T

The clean rinse feel of personal wash products is one of the major technical drivers of consumer preference and usually is measured by in-vivo consumer studies in the consumer goods industry. We report here a custom-made apparatus based on friction and vibration measurements that can be correlated to consumer perceptions of clean rinse feel. The apparatus consists of a rotary stage powered by a motor which is controlled by a programmable controller, a long swiveling arm, an artificial finger, and an underwater sample stage. The artificial finger can adjust the applied normal force on the substrate. The sliding speed of the artificial finger is adjusted and monitored through a computer. Data acquisition software is triggered by the combination of the software and hardware. Four sensors including two normally mounted load cells, an underwater hydrophone and an accelerometer attached to the surface of the artificial finger are used to detect the normal forces, vibration and underwater sound, while the artificial finger slides over the underwater substrate surface and washes the products off from substrate. A friction coefficient can be derived from the data of two load cells and rinse profiles constructed as a function of sliding time. Rinse profiles are shown to be different with application of different cleansers and are correlated to consumer perceptions of slimy or squeaky-clean for different products.

1. Introduction

Typical consumer use of a personal cleanser includes several steps: applying the product to a surface (e.g., skin surface), diluting the product and then lathering, rinsing, drying, etc. In addition to the cleaning function, the in-use sensory perception of personal cleansers is a major technical driver of consumer preference. Particularly, the tactile sensations experienced during the washing process are important in governing a consumer's overall assessment. Changes in the tactile characteristics at the different wash stages cue particular effects, such as rough/smooth, sticky/slippery, slimy/clean feel; and therefore, determine overall product liking.

Washing involves complex natural material surfaces, changing surfactant concentration during rinse, and benefit deposition, etc., which are very difficult to control and reproduce in a laboratory. In the consumer goods industry, consumer study is the accepted means to evaluate a product. But interpretation of the results of these studies can be problematic, particularly with regard to emotional state and personal preference as opposed to real product effects. Personal preference is not only related to the product properties, but also influenced strongly by the persons culture background. For example, Asian consumers, especially in Japan, often desire a certain squeaky clean sensation during rinsing, which cues the perception that the product has been thoroughly rinsed off. In other regions, the same tactile sensation is usually connected to the harsh or soap-like perceptions. Even for the product effect, the skin surface may differ strongly from subject to subject because of age, skin condition, or other factors. Even for a single subject, results may differ from day to day due to use of other products, changing of skin conditions, etc. Most importantly, the high cost, time investment, and legal requirement limit the application of the consumer study (in-vivo), especially in the product development stage when new ingredients are introduced. Therefore, a laboratory test method is desired to study the physical phenomena during using of personal wash products during use.

If we isolate other factors of the washing procedure (for example, fragrance delivery), in this paper, we focus on the characteristics of skin contact during the wash motion. The washing experience strongly relies on contact sensing, for example, applying a product to skin, lathering or rubbing the product on skin surface, followed by rinsing the product off the skin surface and finally feeling the skin after wash. These steps involve heavily with haptic perception.

Haptic perception, one of the fundamental areas of cognitive engineering, has advanced with significant contributions from research in biology, engineering, and psychology [1,2,3,4]. Haptic perception of materials and surfaces relies largely on touch, or tactile sensing. In general, tactile sensing is essential for many applications: textile quality, identification of surface imperfections, robotic, medicine, etc., and attracts researchers from different fields [5,6,7,8,9,10,11,12,13,14,15].

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Force and friction between skin surfaces play important roles in touch perception, with extensive literature devoted to the topic [16,17,18,19,20]. Due to the complexity of the skin surface, and availability of human subjects, many researchers focus on skin-polymer surfaces to understand the skin tribological properties. Those studies are more relevant to texture evaluation [21,7,20].

Tactile sensation is difficult to separate from other sensory aspects, therefore, it should be considered from a multisensory perspective (for review, see ref. [22]). In texture perception, there is no solid consensus on whether vision and touch are an integrated system [23,24]. However, there is general agreement that auditory inputs are important for judgment of texture [25,26,27,28]. Since mechanoreceptors under the skin surface are very sensitive to vibratory stimuli and contribute to tactile perception [29,30,31,32,33,34,35,36,37,38,39,40,41,42], vibration induced by sliding friction is clearly a key to understanding tactile perception [43,44,45]. In Unilever experiments, we found that the skin vibration and sound emission from rubbing fingers and palm across skin surface is highly correlated with perceived skin condition. Through the combination of an acoustic instrument and consumer studies, we have found [46,47] that the squeaky clean perception is connected to the stick–slip phenomena which can be detected via some measurable parameters, such as the surface vibration, sound emitted from the surfaces or friction on the surfaces during sliding of two surfaces against each other.

Better defining the relationship between these measurable physical parameters and consumer "clean" feel during use of personal wash products inspired development of the apparatus reported here. An apparatus that can produce reproducible results within a laboratory that correlate well to the in-use personal perception is highly useful. Most commercial available instruments are based on tribological measurements which correlate poorly to consumer in-use perceptions. We believe that the poor correlation is at least partly due to lack of dynamic acoustic information in the lab data. The present apparatus is related to a previous invention reported in a separate publication [48]; the earlier instrument was built to measure friction simultaneously with dynamic quantities such as accelerations, forces, and sound pressures resulting from light sliding contact over a soft material in air, much like a finger lightly touching a soft material. It can be used to measure the dynamic quantities for leave-on products while the applied product dries. It has a unique capability to measure adhesion between surfaces, which directly relates to the stickiness of a surface. The method can measure and distinguish adhesion between surfaces and overcomes the difficulties associated with measuring friction force between soft surfaces. Use of a pair of force transducers allows the measurement of both the normal contact force and the tangential dissipative force, without interfering with the sliding process. The apparatus described here is similar but can be used underwater. It captures the vibration of a sliding artificial finger, underwater sound and loads, simultaneously. It is thus well suited to evaluate the rinsing profile of personal wash products, and dynamic signals strongly correlate to consumer's in-use perceptions of personal wash products.

This paper details the design of the instrument, its computer control, the required data processing to interpret experiment and demonstration of how a soap base and syndet (synthetic detergent) base cleanser can be reproducibly discriminated.

2. Instrument and materials

2.1. The apparatus

2.1.1. Hardware

A top view of the custom-built apparatus is shown in Fig. 1. The apparatus consists several major components: motor, rotary stage, swiveling arm, "artificial finger", sample stage and water bath. A computer-controlled motor (Emerson NTE-320 motor with Epsilon Eb-205 Digital Servo Drive, Control Techniques., Inc., Eden Prairie, MN) drives a rotary stage through a time-belt which damps noise from the motor rotation. A long swiveling arm fixed to the rotary stage provides near-linear motion; motion is most linear when the arm is much longer than the length of the sample stage. The sample stage, which is immersed into water bath (~50 l), is connected to the table by two load cells (Model AL311 Mid, Range 1000 g, Honeywell, Columbus, OH) which sense the vertical loads with a dynamic range from DC to 300 Hz with the amplifier (Model GM, Honeywell, Columbus, OH) appropriately configured. The water bath is placed on a scissor lifting table (MSC Direct, Melville, NY) for easy height adjustment so the sample stage can be conveniently submerged into or taken out of the water without interfering with any sensors. Near the sample stage, a hydrophone (model 8103, Brüel & Kjær, Norcross, GA, see Fig. 2) is used to detect sound underwater by the moving "artificial finger" sliding across the stationary sample substrate. The hydrophone signal is conditioned by a Nexus Charge Signal Conditioning Amplifier (Brüel & Kjær, Norcross, GA). An accelerometer (352A24, PCB Inc., Depew, NY) mounted on the "artificial finger" just above water detects the vibration of the "artificial finger". To prevent damage from splashed water, we wrapped the accelerometer in a TEFLON tape. The electromagnetic coil attached to the "artificial finger" makes it possible to adjust the finger load during rubbing of the substrate, and to lift up during reverse movement by reversing the voltage

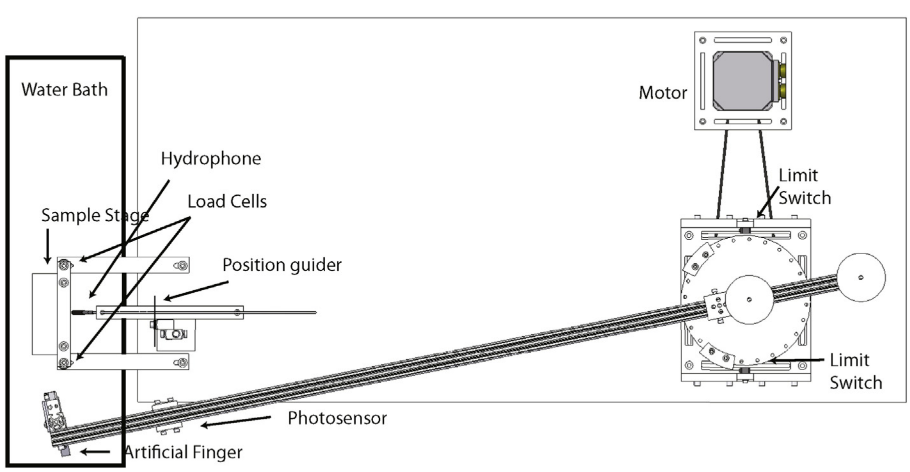

Fig. 1. The top view of the instrument diagram. The right side is the motor and rotary stages which are connected by a time-belt. Two limit switches are fixed in both sides to guide the rotary movement limits. Two round heavy counter-weight metal blocks are on the top of swiveling beam with easy adjustment to balance the beam. The long beam transforms the rotary movement into nearly linear movement for the "artificial finger" on the sample stage. The photosensor is aligned with the position guider which was calibrated to two load cells connected to the sample stage. The above parts are fixed on an optical table. A water bath is put on a cart next to the optical table.

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