Mimicking Sniffing for Improving Machine Olfaction

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***Abstract*— Sniffing is an important component in mammalian olfaction, serving to draw odors into the nose for detection. Reviewing past studies on animal olfaction, certain aspects such as the sniffing frequency have been found to be common among macrosmotic animals. We compared the airflow velocity, volumetric flow during inspiration, and the cross-sectional area of the nasal cavity for various mammals. We find that bigger animals sniff at a lower frequency and each sniff has a higher airflow velocity. Looking at these aspects of sniffing in more detail and understanding the significance of these common values in animal olfaction informs the design of a pre-concentrator to improve performance in machine olfaction.**

I. INTRODUCTION

Olfaction is a form of chemical sensing meant to provide animals with information about their environment. In machine olfaction, electronic devices are made to ”smell” chemicals in the air. This has applications in monitoring pollutants, bomb detection, and noninvasive medical diagnosis [1]–[3].

Macrosmatic animals, such as dogs and elephants, rely heavily on olfaction and have an exceptional sense of smell. Humans have employed these animals to a limited extent for bomb detection and medical diagnosis [4], [5]. It is necessary to understand how these animals achieve such a high level of olfaction if we are to replicate and improve upon these systems. Current strategies in machine olfaction typically require steady airflow and temperature modulation [6], [7], but are often slow because they require the system to reach steady state. Work has been done to accelerate the process by engineering transient features. This includes using sniffing in machine olfaction. When vapors are ”sniffed” at 0.08Hz, higher frequency signals can classify acetone and ethanol [8]. By ”sniffing” at 5Hz, within the range of animal sniffing behavior, detection of TNT vapors can be improved 16 fold [9].

In this review, we compare aspects of olfaction such as the sniffing frequency, volumetric flow, cross-sectional area of the nasal cavity in mammals, and airflow velocity, and consider how this information could help improve uses of sniffing in machine olfaction.

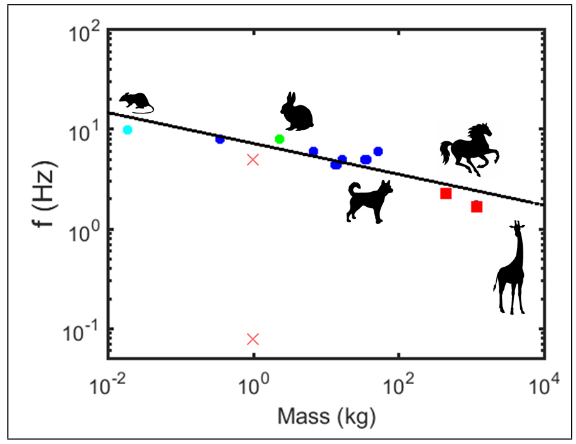

Fig. 1. The sniffing frequency of various mammals were collected from studies (blue [10], cyan [11], and green [12]). We also measured the sniffing frequency of a horse and a giraffe (red squares) from online videos [14] [15]. Sniffing frequency appears to have a weak correlation to body mass, $f \sim M^{-0.15}$, $R^2 = 0.78$. We have also plotted two electronic noses that employ sniffing (red x's) [8] [9]

II. METHODS

The sniffing frequency of various mammals were taken from studies and plotted against their body mass [10]–[12]. We also measured a horse's and giraffe's sniffing frequencies from online videos to gain information on larger mammals [14], [15]. For each video, we timed the length of three separate sniffing bouts. We then listened to the audio to manually count the number of sniffs during the bout and calculated the sniffing frequency.

We analyzed the airflow velocity during sniffing by collecting literature values of volumetric flow during sniffs and the cross-sectional area at the olfactory region with respect to body mass [10], [12], [16]–[19]. From this data, we could approximate a power law curve for the airflow velocity with respect to mass according to the following relationship,

$$v = \frac{Q}{A} \tag{1}$$

where v is the airflow velocity, Q is the volumetric flow rate, and A is the cross-sectional area of the nasal cavity (Fig. 2). We then compared airflow velocities within the animals' nasal cavities, by reviewing data from various numerical fluid dynamics models, only considering the olfactory region for this comparison. Values were read from the figures with use of the color scale bars.

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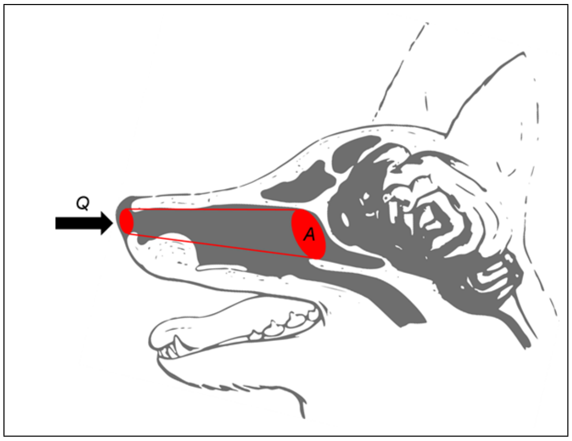

Fig. 2. We collected literature values for the volumetric flow (Q) of sniffs and the cross-sectional area (A) of the nasal cavity at the olfactory region to analyze airflow velocity (v) among mammals.

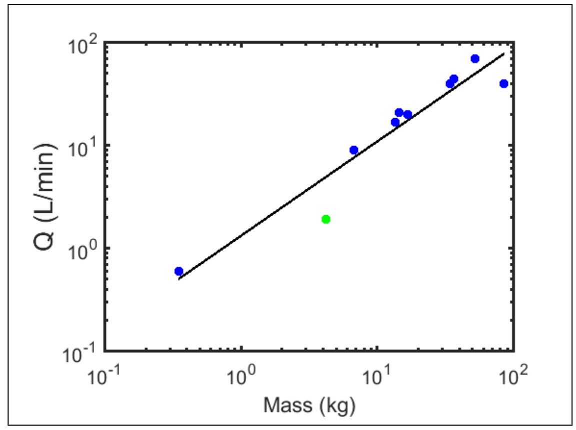

Fig. 3. The volumetric flow during inspiration of sniffs was collected from studies for various breeds of dog, rats, humans (blue markers [10]), and rabbits (green marker [12]). Additional data supports the conclusion that the volumetric flow is a function of mass [10], $Q \sim M^{0.92}$, $R^2 = 0.91$.

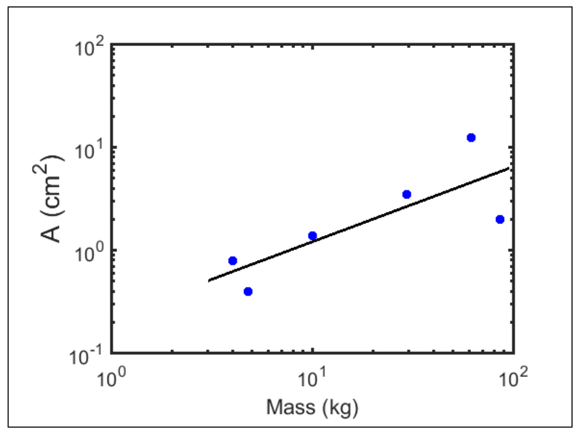

Fig. 4. The cross-sectional area of the nasal cavity at the olfactory region was collected from studies that took MRIs or CT scans of humans, rabbits, dogs, cats, and white-tailed deer [12], [16]–[19]. The cross-sectional area is a function of mass, $A \sim M^{0.73}$, $R^2 = 0.63$

III. Results

Among macrosmatic animals, literature values for sniffing frequency is fairly consistent, between 4-10hz (Fig.1). However, our measurements of a horse's and a giraffe's sniffing frequency are lower, at 2.3Hz and 1.7Hz respectively. This presents a downward trend with respect to mass, giving a power law curve of

$$f \sim M^{-0.15} \tag{2}$$

where f is the sniffing frequency, M is the mass, and $R^2 = 0.79$.

Among dogs, volumetric flow rate increases with respect to mass according to $Q \sim M^{1.03}$ [10]. With the addition of rats, humans, and rabbits, the power law curve is

$$Q \sim M^{0.92} \tag{3}$$

$R^2 = 0.91$ (Fig. 3). From the literature, we also see that the cross-sectional area also increases with mass

$$A \sim M^{0.73} \tag{4}$$

with $R^2 = 0.63$ (Fig. 4). Then according to equation (1), we approximate the following relationship

$$v \sim M^{0.18} \tag{5}$$

When comparing the airflow velocities in the numerical models, there exists a range of velocities in the olfactory region. Dogs and humans seem to have a much more variable velocity range than rabbits and rats do. With this variation, there seems to be a common subrange from 1-2m/s shared by all of these animals.

IV. Discussion

From published data, macrosmatic mammals seem to sniff at similar frequencies. It has been suggested that sniffing at this high frequency allows rats to filter out and attenuate background odors [20]. By sniffing at a higher frequency, the animal brings in new air before previously activated olfactory receptor neurons can reset to detect the next set of molecules. This attenuation allows the animal to detect new unique odors more clearly. However, with the addition of our data on horse and giraffe sniffing frequency, it appears as though there is a slight downward trend in sniffing frequency with respect to body mass. This may be due to potential metabolic constraints in how fast the animal can inspire and expire as their size increases. The sniffing frequency appears constant across species because the dependence on body mass is low.

From the volumetric flow during inspiration (Fig. 3) and the cross-sectional area of the nasal cavity (Fig. 4), we conclude that the airflow velocity increases with the animal's body mass, but there is again only a weak dependence on body mass (Fig. 5). In the numerical models, there is turbulent flow for humans and dogs [10], [13], which results in a wide range of velocities in their contour plots. Due to the wide range of velocities for humans and dogs, there is a common subrange of airflow velocities between 1-2m/s for all of these animals. This common subrange along with the airflow velocity's low dependence on body mass could suggest an optimal velocity range for interactions between

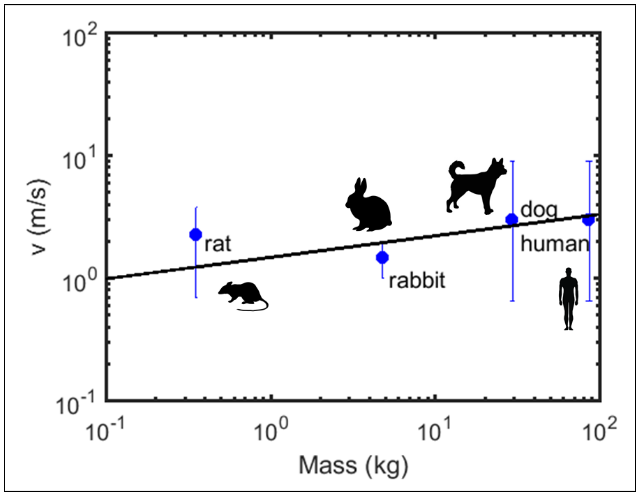

Fig. 5. While the range of airflow velocities in the nasal cavity can be large, every animal has a common sub-range of 1-2m/s. Airflow velocity ranges were read from numerical fluid dynamics models [10], [12], [13]. We approximated a power law curve from the equation $v = \frac{Q}{A}$ where Q is the volumetric flow of a sniff with respect to body mass (Fig. 3), and A is the cross-sectional area of the olfactory region with respect to mass (Fig. 4).

the odors and the receptors.

This data on animal sniffing informs the design of a pre-concentrator for machine olfaction. Using a piston, air can be pulsed in and out at a frequency of 4hz. The air then passes through a valve used to adjust the airflow velocity to 1.5m/s. The resulting signal can be sampled at over twice the sniffing frequency at 10hz. Sniffing will help collect odors on the sensor [9], and DWT will be used to extract features for classification. Such a design could improve transient feature extraction. If in current ongoing experiments, this device proves effective, it will be an important step in employing sniffing for machine olfaction.

V. CONCLUSIONS

A review of mammalian olfaction shows that the sniffing frequency and resulting airlfow velocity are fairly conserved across species. Further investigation into both of these traits is necessary, but a thorough understanding of their significance in animal olfaction may lead to important insights in advancing machine olfaction.

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