Basic Estimation of Internal Power Harvesting in the Mouth Cavity

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Abstract
Many wearable devices for monitoring and maintaining the oral environment are proposed these days. However, the conventional energy supplying method is not practical since the constraint of size and usage. The remarkable progress of the technology about energy harvesting and low power computing have made it possible to develop the small wearable devices without a battery. In this position paper, we would like to propose the energy harvesting model with the calculation of the estimated power generation for the wearable device in the mouth cavity.

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Inertial power harvesting, human-powered devices

ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

Introduction
Mouth is an important organ for the human nutrition, and its role in the people's health is enormous. Thus, it is important in people's health maintenance to monitoring and maintaining the oral environment. Some studies have demonstrated the wearable device for inserting into mouth cavity [3, 4]. This type of wearable device can be mounted without discomfort thanks to its small size and natural shape. How-

ever, the energy supplying method using a battery is not practical since the constraint of size is severe and its removal is difficult.

In this position paper, we introduce the method of energy procurement using energy harvesting technology in the mouth cavity. We described the modeling and expected power calculation of the energy harvesting method by using a bimorph type piezoelectric element. Moreover, we examine the available sensors and possible applications in that situation.

Related Work

The research about low-power computing technology has progressed in recent years. Table.1 shows the required power for several types of sensors. From this table, we can

Table 1: Required power for components in consumer mobile devices and health sensors.[8]

Electronics	Required Power
RF receiver chip	24 mW
PPG sensor	1.473 mW
Humidity	1 mW
Pressure	0.5 mW
3D accelerometer	0.324 mW
Temperature	27 µW
Wristwatch	7 µW
Memory R/W	2.17 µW
A-D conversion	1 µW
RF transmission	sub µW

perform sensing and data logging if we generate more than several µW power.

It has been proposed that the human-power harvesting method by using an electret [8] or a piezoelectric element [6]. The speed of chewing is a several Hz [5]. Thus the method using piezoelectric element is suitable in this case.

Modeling and Expected Power Calculation

We can define the size of a tooth by the mesiodistal tooth crown dimensions and the buccolingual tooth crown dimensions. The average value of the mesiodistal tooth crown dimension of a second molar tooth is 10.13 mm, and that of buccolingual is 8.96 mm [1]. This size is tiny compared to the conventional wearable device, and it is also difficult to remove it for charging. Thus, it is difficult to apply the regular battery in these wearable devices.

Therefore, we consider the power generation method by using human-power harvesting since it does not need to be charging. We select the model for power generation using a bimorph type piezoelectric element and chewing power since the speed of chewing is slow. The calculation of the amount of power generation when the bimorph element is vibrated with a constant displacement is shown below. The strain at x appears as below when we put the pressure on a fixed end as $S_0 \exp(j\omega t)$ and that of opposite side as $\beta S_0 \exp(j\omega t)$ [2].

$$S_x(x) = (1 - \frac{1-\beta}{L}x) S_0 \exp(j\omega t) \quad (1)$$

Piezoelectric equations are given as below.

$$S_x = s_{11}^E T_x + d_{31} E_z \quad (2)$$
$$D_z = d_{31} T_x + \epsilon_{33}^T E_z \quad (3)$$

, where S_x is the strain in x direction , T_x is the stress in x direction, E_z is the electric field in z direction, D_z is the electric displacement in z direction, s_{11}^E is the elastic compliance in the constant electric field, ϵ_{33}^T is the permittivity when the stress is constant, d_{31} is the piezo stress constant.

The peak values of voltage and current of the circuit are given as below.

$$V_p = -\int E_z d_z = -hE_z \quad (4)$$

$$i_p = \frac{d}{dt}(\iint D_z dxdy) = j\omega \iint D_z dxdy \quad (5)$$

We obtain the equation below from Eq.(2) and (3):

$$\begin{aligned}\iint D_z dxdy &= d_{31} \iint T_x dxdy + WL\,\epsilon_{33}^T E_z \\ &= \frac{d_{31}}{s_{11}^E} \iint S_x dxdy + WL\,\epsilon_{33}^T (1 - \frac{d_{31}^2}{\epsilon_{33}^T s_{11}^E}) E_z\end{aligned} \quad (6)$$

From Eq.(1), we obtain the equation below:

$$\begin{aligned}\iint S_x dxdy &= WS_0 \int_0^L (1 - \frac{1-\beta}{L} x) dx \\ &= \frac{WL(1+\beta)S_0}{2}\end{aligned} \quad (7)$$

We derive the relational expression of electrical circuit from Eq.(2) and (3):

$$\begin{aligned}i_p &= j\omega \frac{d_{31} WL(1+\beta)S_0}{2s_{11}^E} - j\omega \frac{WL\epsilon_{33}^T}{h}(1 - \frac{d_{31}^2}{\epsilon_{33}^T s_{11}^E})V \\ i_p &= \frac{V}{R}\end{aligned} \quad (8)$$

Then, V_p and $|V_p|$ are calculated as below:

$$V_p = \frac{j\omega \frac{d_{31}}{s_{11}^E} \frac{1-\beta}{2} WLS_0}{\frac{1}{R} - j\omega \frac{\epsilon WL}{h}} \quad (9)$$

$$|V_p| = \frac{\omega \frac{d_{31}}{s_{11}^E} \frac{1-\beta}{2} WLS_0 R}{\sqrt{1 + \omega^2 R^2 \epsilon \frac{W^2 L^2}{h^2}}} \quad (10)$$

,where

$$\epsilon = \epsilon_{33}^T (1 - \frac{d_{31}^2}{\epsilon_{33}^T s_{11}^E})$$

P_{peak} can be calculated as below:

$$P_{peak} = \frac{|V|^2}{R} = \frac{(\omega \frac{d_{31}}{s_{11}^E} \frac{1-\beta}{2} WLS_0)^2 R}{1 + \omega^2 R^2 \epsilon^2 \frac{W^2 L^2}{h^2}} \quad (11)$$

We can calculate the estimation of the peak power by this formula and the constants below. We defined the sample value of chewing frequency as 1 Hz from the previous research [5].

$$\begin{cases} \omega = 2\pi \times 1 \\ R = 200\ \mathrm{k\Omega} \\ W = 10 \times 10^{-3}\mathrm{m} \\ L = 9 \times 10^{-3}\mathrm{m} \\ h = 1 \times 10^{-3}\mathrm{m} \\ d_{31} = -197 \times 10^{-12} \\ \epsilon_{33}^T = 2127 \times 8.854 \times 10^{-12} \\ s_{11}^E = 17.0 \times 10^{-12} \\ S_0 = 1.64 \times 10^{-3}\mathrm{m} \\ \beta = 0\ (\text{worst case}) \end{cases}$$

,where the concentrated load value on the element is 83.35 N [7] for calculating S_0 and sample physical properties of the piezoelectric element are from the data of P-10 (FDK).

With these values, P_{peak} is calculated as 5.77 µW. Table. 1 shows that we can perform the logging and infrequent transmission of data by this power if we use low power MCUs. Moreover, we can measure the body temperature if we can obtain a little more power.

Conclusion

In this paper, we introduced the concept energy harvesting method for artificial tooth type wearable devices in the mouth cavity. We cannot use a normal battery for the size and charging issues in this situation; therefore, we discussed the energy harvesting method by using a piezoelectric element. We designed the model for power generation using a bimorph type piezoelectric element and estimated the amount of power generation by substituting physiological and physical parameters.

As a result, the expected power generation from the power of bite is calculated as 5.77 µW. This amount of power generation enables us to perform the logging and infrequent transmission of data if we use low power MCUs. This result suggests that our proposed devices can be applied to health care monitoring of mouth such as counting the number of chewing. Meanwhile, not very strong force is premised on this model since we use the model of the common piezoelectric element. Thus, we may design the more efficient power harvesting model when we take account of the locally strong force since the strength of bite must be stronger than that of normal pressing.

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