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Inductive Communication and Localization of Wireless Sensors in Photoreactors

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Summary:

We propose a method for inductive communication and localization of wireless sensors in photoreactors. In past, methods for internal illumination of photoreactors have been presented. Wireless light emitters (WLE) have been developed to counteract the limited penetration depth of light in photoreactors. Photoreactors are used to cultivate photosynthetic active microorganisms and cells or to perform photocatalytic reactions. The WLE are powered from outside the reactor through a loosely coupled inductive link. The intermediate frequency (178 kHz) electromagnetic field with a magnetic flux density of approx. B = 1 mT is produced by multiple coils driven by an Class-E amplifier [1]-[3]. The next step is the inclusion of sensors to measure crucial parameters such as e.g. temperature, pH-value or oxygen and carbon dioxide concentrations in order to control the various processes. Additionally the information about the position of the sensor inside the photoreactor leads to a spatial resolution of the measured parameter.

Keywords: inductive communication, inductive localization, wireless sensors, photoreactor, 3d-coil

Introduction

To control the processes in those photoreactors various parameters have to be measured e.g. temperature, pH-value, UV-illumination or other chemical concentrations. To counteract the drawback of measuring the named parameters only at one point inside the photoreactor, we present methods for the wireless communication and localization of wireless powered, unfixed sensors. Because of the promising propagation properties of magnetic fields in water and in salty water, we chose the inductive layer for the communication and the localization task. The authors of [4] also make use of this advantage for the inductive communication through human tissue for assistive listening devices. For our photoreactor use, we set the modulation frequency at a factor 1.66 above the frequency of the power link in order to prevent interferences by harmonics. We also will take the standard frequencies like 433 MHz in consideration; this frequency band is used as a communication layer in a similar project [5]. The drawback of higher frequencies is their high damping factor in electrically conducting media.

Inductive OOK communication

As modulation technique for the data transmission, we use the on-off-keying (OOK); this is implemented like in [4] with an on-off switched Hartley-oscillator as transmitter. In a first step, in order to simulate the single sensor data bits we use the integrated circuit LMC555 to generate the on-off signal. As a receiver, we use an LC-tank tuned to the same frequency as the Hartley-oscillator.

Inductive sensor localization

To solve the localization task of the transmitting coil, we make use of the well-defined spatial propagation of the magnetic dipole field. As shown in [6], the magnetic field of an one-loop coil, excited with the current $i = I\cos(\omega t)$, at a position defined by the distance x from the loop center and the off-axis angle φ, is completely described by its radial (1) and tangential (2) components. N is the number of turns and A the area of the coil.

$$H_r = \frac{NIA}{2\pi x^3}\cos\varphi \qquad (1)$$

$$H_t = \frac{NIA}{4\pi x^3}\sin\varphi \qquad (2)$$

If the transmitter and the receiver have the same orientation (x-axis aligned, y- and z-axis parallel), the transmitter-receiver coupling is described by the Eq. (3). $\boldsymbol{f_{tx}}$ is the receiver signal vector, $\boldsymbol{f_{rx}}$ the transmitter signal vector; x is the distance between them and C is a constant factor derived from the coil properties and the sensor gain [6].

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$$\boldsymbol{f_{rx}} = \left(\frac{C}{x^3}\right) \boldsymbol{S}\, \boldsymbol{f_{tx}} \qquad (3)$$

$$\boldsymbol{S} = diag(1, -0.5, -0.5)$$

We have simplified the localization task by assuming that the transmitting coil is always aligned with the vertical z-coordinate like shown in Fig. (1) (in general, this alignment of the transmitter is important also for the power link). Measuring the magnetic field components in the x- y- and z-direction at one known spatial point allows us to calculate a direction vector $\boldsymbol{r}$ that points from the measuring point to the position of the transmitter. Making use of the spherical coordinate system, this direction vector is defined by two angles α and β; α represents the rotation angle around the z-axis, β the rotation around the y-axis. The coupling between transmitter and receiver is defined by Eq. (4). $\boldsymbol{f_{tx}} = (0\ 0\ a)^T$ is the signal vector of the transmitter. It is an unknown value in z-direction since the current in the transmitter coil is unknown (it depends on the position of the transmitter in the photoreactor). $\boldsymbol{T_\alpha}$ is the rotation matrix around the z-axis and $\boldsymbol{T_\beta}$ the rotation matrix around the y-axis and $\boldsymbol{f_{rx}}$ is the vector with the measured x- y- and z-components of the transmitter magnetic field at receiver side.

$$\boldsymbol{f_{rx}} = \left(\frac{C}{x^3}\right) \boldsymbol{T_\alpha^{-1} T_\beta^{-1} S T_\beta T_\alpha f_{tx}} \qquad (4)$$

The angles α and β of the direction vector $\boldsymbol{r}$ in spherical coordinates (and the value a) can be calculated by solving the equation system (4).

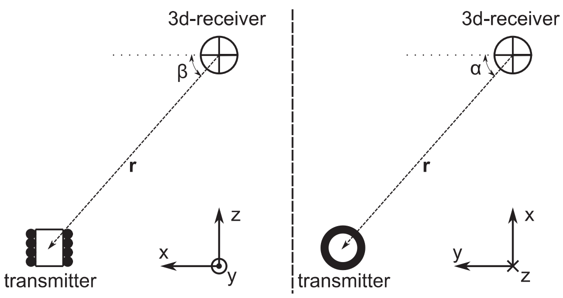

Fig. 1. Alignment of transmitter and receiver

Results

We performed measurements with a 3d-receiver. This receiver consists out of three identical LC-tanks with the coils positioned orthogonally to each other. The measured signals are digitalized using the *National Instruments USB-6366* I/O device. The software *Matlab* is used to control the I/O device and for solving the Eq. (4). The measurements for the angle α were performed with a constant distance of 28 cm between transmitter and receiver; the results are shown in Fig. (2).

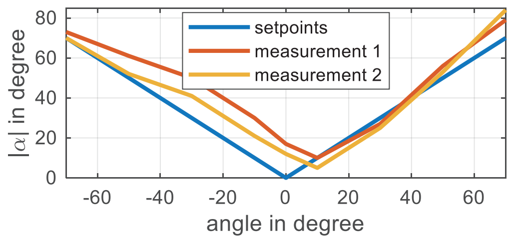

Fig. 2. Setpoints and measured angles for α

Discussion

The feasibility is proofed by the measurements illustrated in Fig. (2), the results on one side of the receiver are more accurate than on the other. This property needs closer investigations. Since we get multiple solutions for the angles α and β by solving the Eq. (4), the next step is to automate the task of finding the correct solution. The exact transmitter position can be found by adding one or more 3d-receivers at different places. This leads to multiple direction vectors from known positions. Finding the point of minimal distance between them should lead us to the exact transmitter position.

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