Technical note

Phase- and amplitude-dependent stimulation at high sample frequency

Keywords—Amplitude, Phase, Rhythm, Stimulation

1 Introduction

To investigate the presence and type of a nonlinearity, it may be fruitful to stimulate a (e.g. physiological) system at different phases and amplitudes of a recorded narrow-bandpass stochastic signal (e.g. physiological rhythm). Furthermore, to estimate the response to a stimulus from recordings corrupted by an additive narrow-bandpass stochastic signal, it is fruitful to average results from stimuli given at opposite phase and same amplitude for the main frequency component. Each of these goals could be reached by a sufficient number of random stimuli. However, more accurate results would be obtained from fewer stimuli by stimulating at predetermined phase and amplitude intervals. Such stimuli also may be useful for impulsive control applications.

This paper describes a simple procedure for phase- and amplitude-dependent stimulation, with little computation and hence the possibility of a high sample frequency.

2 Theory

A narrow-bandpass stochastic process may be described as

$$y(t) = A(t) \cos \phi(t) \quad (1)$$

Fig. 1 Representation of phase ϕ and amplitude A in the y - z plane

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with amplitude $A(t)$ which does not vary significantly during one period, and phase

$$\phi(t) = 2\pi F(t)t + \phi_0 \quad (2)$$

with frequency $F(t) \approx F_0$. Then it follows from eqns. 1 and 2 that

$$z(t) = 2\pi F_0 \int_0^t y(\tau) d\tau \approx A(t) \sin \phi(t) \quad (3)$$

Hence, from eqns. 1 and 3

$$\phi(t) = \arccot \frac{y(t)}{z(t)} \quad (4)$$

$$A(t) = \sqrt{y^2(t) + z^2(t)} \quad (5)$$

This relation of z , y , ϕ and A is illustrated in Fig. 1.

3 Equipment

The experimental setup is shown in Fig. 2. A preamplifier with gain G_1 may be used to adapt the amplitude of the measured signal $v(t)$ to the integrator input requirements. The amplified signal $w(t)$ contains d.c. and very low-frequency drift components. The time integral of those would drive an

Fig. 2 Experimental setup

ideal integrator into saturation. Therefore, because of the narrowband character, lower frequencies may be filtered out by application of a high-fidelity a.c. integrator (PHILBRICK, 1968). This yields

$$x(t) = G_2 \int_0^t w(\tau) d\tau \quad (6)$$

which is inversely proportional to frequency F_0 (eqn. 3). Therefore, to obtain good signal-to-noise ratio and prepare for $z(t)$ according to eqn. 3, it is necessary to choose as gain ratio

$$G = \frac{G_2 G_4}{G_3} = 2\pi F_0 \quad (7)$$

The final gains G_3 and G_4 may adapt the signal levels to the ADC range. The gains G_1 – G_4 may each be chosen for optimal signal-to-noise ratio, or G_1 and G_3 may be adapted to omit G_2 and G_4 .

4 Gain adaptation to F_0

The gain ratio G (eqn. 7) depends on F_0 and therefore should be chosen such that the amplitudes of $y(t)$ and $z(t)$ are equal. A simple procedure is to adjust G_2 , G_3 and/or G_4 until the point (y, z) describes radial symmetric spirals in the plane shown in Fig. 1, visualised on an XY oscilloscope. It is also possible to use a program which samples y and z and shows the ratio between the mean absolute values of y and z . If the used gain ratio is entered, the required gain ratio can be computed.

5 Stimulation program

The program should trigger the stimulator if both

$$\phi_1 < \phi \leq \phi_2 \quad (8)$$

$$A_1 < A \leq A_2 \quad (9)$$

for given bounds ϕ_1 , ϕ_2 , A_1 and A_2 . Online calculation of ϕ and A according to eqns. 4 and 5 between samples would limit the sample frequency unnecessarily. Less computation would

be needed to check the equivalent of eqns. 8 and 9 from eqns. 4 and 5;

$$\cot \phi_1 < \frac{y}{z} \leq \cot \phi_2 \quad (10)$$

$$A_1^2 < y^2 + z^2 \leq A_2^2 \quad (11)$$

together with a sign test of y or z . This still would require division and squaring.

These time-consuming operations are not required in the following procedure, which is illustrated in Fig. 3. Before the experiment, a program is run which uses ϕ_1 , ϕ_2 , A_1 and A_2 to calculate bounds y_1 , y_2 , y_3 , y_4 , and y_1 – y_4 used to compute the lower and upper limits $l(y)$ and $u(y)$, which z should be between to trigger the stimulator. These limits are truncated to integer values and stored in arrays of dimension y_4 – y_1 . These arrays may be stored on disc beforehand for minimal experiment time.

During the experiment, for each sample y is checked to see whether it is between y_1 and y_4 . If so, it is checked whether z is between $l(y)$ and $u(y)$. Thus, only 2 array lookups and 2–4 integer IF-statements are needed. For compilers which do not allow negative array subscripts, a different program may be run for segments in the left half plane checking $l(-y)$ and $u(-y)$. Then segments covering both left and right hand plane require a check of the sign of y , followed by a jump to the adequate program part. Segments covering both upper and lower half planes require a reversed role of y and z .

6 Sample result

This procedure was implemented in BASIC on an 8k 12-bit computer with 1.2 μ s cycle time and 10-bit ADC (DEC Lab 8E). Each segment remained within one quadrant of the y – z plane. The slowest segment test took less than 9 ms including sample storage, so that more than 111 samples per second could be checked. Thus e.g. a 9 Hz rhythm could be stimulated within 1 cycle in any of 12 segments of 30° at the right amplitude range, as this requires $12 \times 9 = 108$ samples per second. A more complicated 100 samples per second version was applied to Parkinson tremor (LÖHNBERG *et al.*, 1981). Higher frequencies should be possible in machine language or with more sophisticated computers.

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Fig. 3 Test of whether z is between $l(y)$ (solid line) and $u(y)$ (broken line)