offset. The current gain performance can further be improved by using a layer structure with lower sheet resistance, optimised mobility against density and shorter gate length. The high gate resistance of the devices, R_g = 1.42kΩ/mm, leads to a degradation of f_{max} compared to the results in [2] and significant improvement is expected by using a T-gate configuration. Our results also clearly show that devices with high values of f_T and f_{max} can readily be achieved by using a non-symmetric source-gate-drain configuration to increase the C_{gs}/C_{gd} ratio and decrease the source access resistance.

In conclusion, we have demonstrated the operation of n-channel MODFETs fabricated on Si/SiGe heterostructures grown by UHV-CVD with extremely high unity current gain cutoff frequencies. Values of f_T = 47GHz and f_{max} = 55GHz were obtained in devices with L_g = 0.2μm and L_{ds} = 0.9μm. For devices with L_g = 0.2μm, L_{ds} = 0.5μm, the value of f_T = 62GHz, obtained at a bias voltage of only V_{ds} = + 1.0V is the highest unity current gain cut-off frequency for any n-channel Si/SiGe MODFET reported in the literature. Both geometries also had considerably improved off-state current compared to typical Si/SiGe n-MODFETs in the literature. Further improvement in f_T and f_{max} are expected with layer structure improvements and device design optimisation. The results clearly demonstrate the suitability of UHV-CVD grown Si/SiGe MODFETs for high-speed low-power RF and microwave applications.

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Algorithm for robot position tracking using ultrasonics

W.T. Kuang and A.S. Morris

Extending previous work on ultrasonic robot tracking, a new geometric position-calculation algorithm is introduced. This removes the need to locate the ultrasonic receivers at fixed positions on orthogonal axes, equidistant from the origin, and offers substantial advantages in terms of improved accuracy and flexibility.

Introduction: The low cost and potentially good measurement accuracy of ultrasonic systems make them an attractive choice for tracking the motion of a robot end-effector. However, the triangulation algorithm described in [1] for calculating robot position requires very accurate location of ultrasonic receivers at fixed points along orthogonal axes and equidistant from the origin of a reference co-ordinate system established in the robot workspace. In practice, such accurate positioning of the receivers is very difficult to achieve. The alternative geometric algorithm described below allows free choice of location of the ultrasonic receivers at any convenient points in the robot workspace, leading to substantially better measurement accuracy.

Review of triangulation technique: Referring to Fig. 1, the basis of ultrasonic position measurement is to mount an ultrasonic transmitter on the monitored point P (commonly the robot end-effector tip) and then measure the transmission times of ultrasonic energy bursts to ultrasonic receivers located at points S_1, S_2 and S_3. S_1 is at the origin and S_2, S_3 are at distances d and e, respectively, along the x and y axes of an orthogonal co-ordinate system. As the speed of ultrasound through air is known, the distances a, b, c and thus the x, y, z co-ordinates of P can be calculated:

$$x = (a^2 + d^2 - b^2)/2d \qquad y = (a^2 + e^2 - c^2)/2e$$
$$z = \sqrt{a^2 - x^2 - y^2} \qquad (1)$$

Any positioning errors in the receivers reduce the accuracy of the system. Also, the need for the receivers to be at precise positions seriously limits the adaptability and flexibility of the system, particularly if the number of receivers is increased beyond three. More than three receivers are normally required to maintain the ability of the system to measure position when the transmission path to one or more receivers is obstructed, and, for example, Fig. 2 shows a system with eight receivers located at the corners of a virtual cube around the robot [2], which allows the best three signals received to be used in calculations.

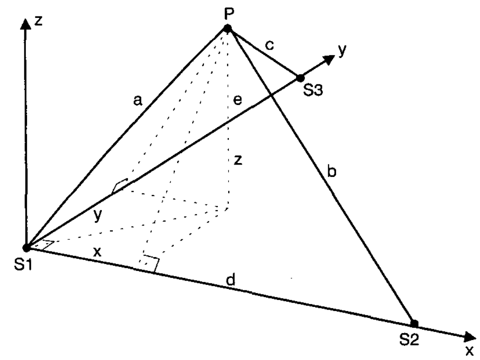

Fig. 1 *Triangulation technique*

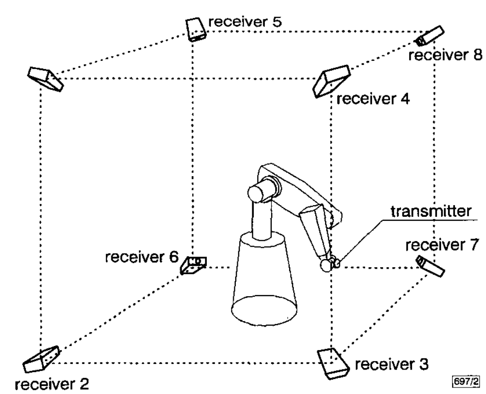

Fig. 2 *Arrangement of receivers*

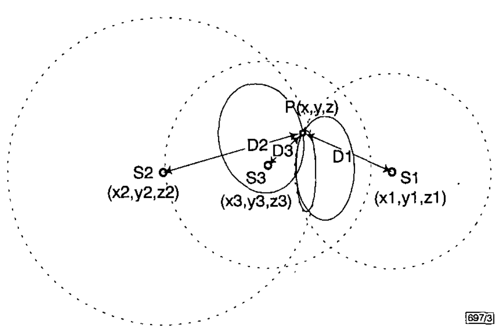

Fig. 3 *Algorithm for co-ordinate determination of end-effector*

New algorithm: Fig. 3 shows three receivers placed arbitrarily at three known positions denoted as $S_1(x_1, y_1, z_1)$, $S_2(x_2, y_2, z_2)$ and $S_3(x_3, y_3, z_3)$. $P(x, y, z)$ is the position of the end-effector and D_1, D_2 and D_3 are the measured distances between the end-effector and the receivers.

For each receiver S_i (i = 1, ..., 3), a sphere with centre S_i and radius D_i, with P on its circumference, is given by

$$(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2 = D_i^2 \qquad (2)$$

For three receivers, eqn. 2 represents a system of three equations which can be solved to obtain the co-ordinates of P by applying a Newton iteration given by eqn. 3. Only three or four iterations are required to solve for P.

$$x_{n+1} = x_n - F(x_n)^{-1} f(x_n) \qquad n \geq 0 \qquad (3)$$

where each term in eqn. 3 corresponds to a matrix:

$$x_{n+1} = \begin{bmatrix} x_{1,n+1} \\ x_{2,n+1} \\ \vdots \\ x_{k,n+1} \end{bmatrix} \quad x_n = \begin{bmatrix} x_{1,n} \\ x_{2,n} \\ \vdots \\ x_{k,n} \end{bmatrix} \quad f(x_n) = \begin{bmatrix} f_1(x_n) \\ f_2(x_n) \\ \vdots \\ f_k(x_n) \end{bmatrix}$$

$$F(x_n) = \begin{bmatrix} \frac{\partial f_1(x_n)}{\partial x_1} & \frac{\partial f_1(x_n)}{\partial x_2} & \cdots & \frac{\partial f_1(x_n)}{\partial x_k} \\ \frac{\partial f_2(x_n)}{\partial x_1} & \frac{\partial f_2(x_n)}{\partial x_2} & \cdots & \frac{\partial f_2(x_n)}{\partial x_k} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial f_k(x_n)}{\partial x_1} & \frac{\partial f_k(x_n)}{\partial x_2} & \cdots & \frac{\partial f_k(x_n)}{\partial x_k} \end{bmatrix}$$

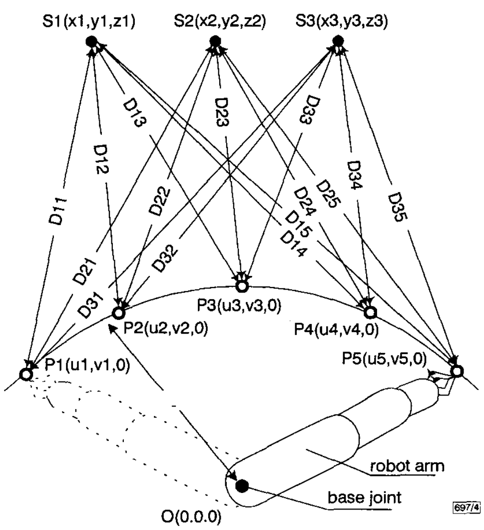

Fig. 4 *Algorithm for determining position of receivers*

Algorithm for determining receiver positions: Once the receivers have been conveniently placed, their positions must be accurately determined to allow calculation of the co-ordinates of P. The basis of the algorithm, which is simple and efficient and does not use any extra equipment, is to use the receivers to collect data for a known trajectory of the robot end-effector. The chosen trajectory is an arc, which is made by rotating the base joint through a certain angle and keeping all other joints fixed. In Fig. 4, P_j, j = 1, ..., 5, represent five points on the arc trajectory of radius 'r', the origin of which, 'O', is at the base joint. The three receivers are located at unknown positions S_i, i = 1, ..., 3. The distances between the points P_j and receivers S_i are calculated from transmission times and denoted as D_{ij}. Since the arc trajectory is on the same plane as O, the co-ordinates of the points P_j on the arc can be represented as $(u_j, v_j, 0)$, where u and v are related to r by

$$u^2 + v^2 = r^2 \quad \Rightarrow \quad v = \sqrt{r^2 - u^2} \qquad (4)$$

Thus, each v_j parameter can be expressed in terms of r and u, and only six variables, $u_1 - u_5$ and r, are needed to represent the co-ordinate positions of the five measured points P_j. As already discussed, from the view of each receiver, each measured point is on a sphere expressed by eqn. 2. So, in this case, where three receivers measure five points, 15 equations can be established to evaluate the 15 unknowns, i.e. $u_1 - u_5$, r and the x, y, z co-ordinates of S_1, S_2, S_3:

$$(x_1 - u_1)^2 + \left(y_1 - \sqrt{(r^2 - u_1^2)}\right) + z_1^2 = D_{11}^2 \quad \text{etc.} \qquad (5)$$

Conclusion: A new algorithm has been described which replaces the traditional triangulation technique for co-ordinate determination of robot manipulators used in previous ultrasonic tracking systems. This new algorithm makes the tracking system much easier to set up and use and brings significant benefits to the system of much better accuracy, flexibility and adaptability. Apart from applications in ultrasonic systems, this improved algorithm is also relevant to other robot tracking systems that currently use triangulation techniques.

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Higher-order time-varying allpass filters for signal decorrelation in stereophonic acoustic echo cancellation

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A new technique is presented for decorrelating the input signals in stereophonic systems by means of time-varying allpass filters. The controllable and almost linear phase response of higher-order allpass filters is exploited in this context and a particular type of time variation is used to vary the parameters of such filters. Simulation results are presented based on real stereophonic signals and supported by subjective listening tests.

Introduction: Stereophonic acoustic echo cancellation (SAEC) is a difficult problem. The strong correlation between stereo signals impacts greatly on the ease with which the receiving room impulse responses may be identified. Several techniques have been proposed for decorrelating the input signals which result in different levels of sound degradation [1, 2]. An allpass filter alters only the phases of the input signals while leaving their magnitudes undisturbed, and this property can be employed to advantage in an effort to decorrelate stereo signals. A first-order time-varying allpass filtering approach has already been introduced in [3]. However, the update equation for the time-varying parameter $\alpha(n)$ and the choice of the interval limiters α_{max} and α_{min} employed in [3] result in poor sound quality. The sound degradation is also due to the nonlinearity of the phase responses in the first-order allpass filters used. The property that higher-order allpass filters can more closely preserve phase linearity is the motivation for the higher-order time-varying allpass filtering technique for signal decorrelation proposed in this Letter. In addition, an improved approach to varying the parameters of the allpass filters is introduced so as to yield better sound quality.

Time-variation of allpass filters for signal decorrelation: An approach to achieving decorrelation involves passing the signals $\mathbf{x}_1$ and $\mathbf{x}_2$, through time-varying first-order allpass filters $\mathbf{a}_1(\mathbf{n})$ and