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A NEW AIRCRAFT INTEGRATED POSITIONING AND COMMUNICATION SYSTEM BASED ON SATELLITE

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ABSTRACT

Positioning system based on satellite in developing and application are reviewed. By using Very Small Aperture Terminal (VSAT) technology, a new scheme of integrated positioning and communication system based on satellite is presented in the paper. The dynamic mathematical model of the system has been derived. In order to improve the precision of Kalman filter algorithm in calculation, adaptive filtering estimations of acceleration mean and noise Variance are proposed. Futher studies show that the U–D fractorization algorithm is efficient in improving the accuracy. Further studies show that the U–D fractorization algorithm is efficient in improving the accuracy and numerical stability. The computer simulation study indicate that the utilization of various improved Kalman filter algorithms is successful.

Ⅰ. INTRODUCTION

Space positioning technology is applied widely in navigation, scout, rescue, survey and etc. At present, new generation of global satellite–based navigation systems are being developed, which are GPS (U.S.A), GLONASS (U.S.S.R), NAVSAT (ESA) and other. These systems are consist of complete satellite configuration. They are costly and cannot content with the need in vast communications.
Satellite–based positioning systems have been studying in China since 60′s. The demonstration of double satellite fast positioning fixing communication system (similar to the GEOSTAR system of U.S.A) have been identified up to date. In order to provide various communication and positioning capability flexiblely, the research puts forward to a new scheme of using VSAT network to finish accurate positioning and communication in a large area. In caculation, adaptive filtering estimations of acceleration mean and noise variance are adopted. The U–D fractorization algorithm accelerates computation convergence and has good stability as well as good positioning precision.

Ⅱ. SYSTEM DISCRIPTION

VSAT network is a new creative and special kind of wide–covering range, thin–route satellite network in the field of satellite communications. Because of cheapness, minimal antenna (typically antenna diameter of 1.8 to 2.4 meters for each VSAT station), quantity reliability and flexible construction, it is widely used in transportation, finance, news and education department as a data transmition system.

The system is a star network which consists of one satellite, one hub earth station with a huge computer connections to many remote customer′s VSAT headquaters, each of which is defined as a basic station of mobile radio communication. A VSAT can exchange messages with the users within its coverage.

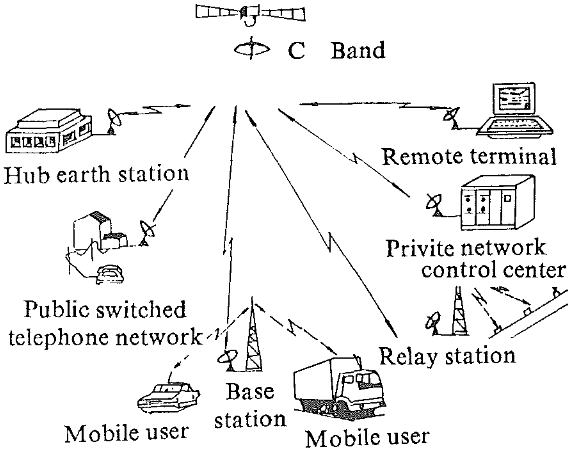

Figure 1 system configuration

Pseudoranges surveying is used in positioning with two pseudoranges from a user to one VSAT base station and another obtained through interrogation and responding. Three spherical surface intersecting is selected to get two intersections which is mirrored each other. One intersection is user's real location, the other is hazy solution. Thus the pseudorange which is from the user to the satellite would be obtained. Figure 2 shows the trends of the information link.

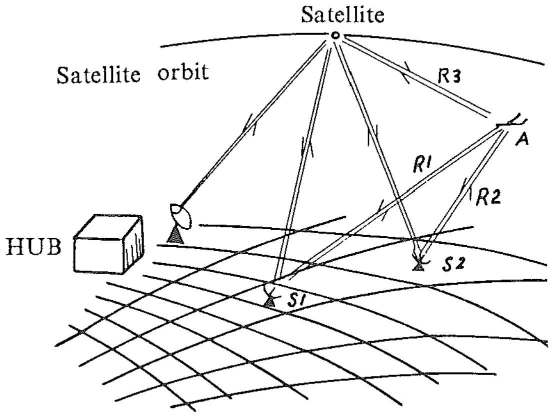

Figure 2 Trends of the information link

Ⅲ. MATHEMATICAL MODEL

During the peroid of signal propagation, various noises and errors were brought about by observing equipment, then kalman filtering is used to improve the precision in positioning caculation, also when the dynamic model is uncertain.

The observing parameter in positioning system is pseudorange r*

$$\begin{aligned} r^{*} &= [(r_i sin\theta_i cos\Phi_i - r_o sin\theta_o cos\Phi_o)^2 \\ &+ (r_i sin\theta_i sin\Phi_i - r_o sin\theta_o sin\Phi_o)^2 \\ &+ (r_i cos\theta_i - r_o cos\theta_o)^2]^{1/2} + \beta\omega(k) \\ &= [(x_i - x_o)^2 + (y_i - y_o)^2 + (z_i - z_o)^2]^{1/2} \\ &\quad + \beta\omega(k) \\ &= r + \beta\omega(k) \end{aligned} \tag{1}$$

Where ri, Qi and Φi separately stand for the distance from known point to unknown point, geographical longitude and geographical latitude. W(K) is the observing noise while β is a coefficient. (X, Y, Z) is Cartesian coordinates values in accordance. The state variable is

$$Z = [X \ \dot{X} \ \dot{X} \ Y \ \dot{Y} \ \dot{Y} \ Z \ \dot{Z} \ \dot{Z}]$$

Here we make use of zero–mean correlated acceleration model advanced by R.A. Singer. The noise of maneuvering is enbodied in the disturbance of acceleration. One dimention acceleration correlated function is:

$$r(\tau) = E[a(\tau)a(t+\tau)] = \sigma_m^2 e^{-\alpha_i|\tau|}$$
$$\alpha_i \geqslant 0, \quad i = 1,2,3$$

Where σ_m^2 is the target location acceleration variance. The extended state equation of continuous moving target is:

$$\dot{X}(t) = AX(t) + BW(t)$$

W(t) is a white noise with a variance of $2\alpha\sigma_m^2$

In terms of observing, our system mainly serves for civil users. Its coverage is broad and the user's requirement about positioning is different, especially as the basic station of mobile communication. Suppose the sampling periods are $\tau_1, \tau_2, \cdots, \tau_k$. Discrete state equation is:

$$X(K) = \Phi(K|K-1)X(K-1) + \omega(K-1)$$

$$\Phi(K|K-1) = \begin{bmatrix} [\Phi_1] & 0 & 0 \\ 0 & [\Phi_2] & 0 \\ 0 & 0 & [\Phi_3] \end{bmatrix}$$

Where

$$[\Phi_i] = \begin{bmatrix} 1 & \tau_k & (1+\alpha_i\tau_k + e^{-\alpha_i\tau_k})/\alpha_i^2 \\ 0 & 1 & (1-e^{-\alpha_i\tau_k})/\alpha_i \\ 0 & 0 & e^{-\alpha_i\tau_k} \end{bmatrix}.$$

By defining

$$\omega(\tau_k) = \int_{\tau_{k-1}}^{\tau_k} e^{A(\tau_k-\tau)} B\omega(\tau)d\tau \quad and$$

$$\theta(\tau_{k-1}) = E[\omega(\tau_{k-1})\omega^T(\tau_{k-1})]$$

the value of θ is getted. Both Φ and θ are time–varying parameters. It's obvious that the equation getted from formula (1) is non–linear. In observing equation.

$$y(k) = H(k)X(k) + V(k)$$

the linear model about H(K) is:

$$H(k) = \frac{\alpha H(k)}{\alpha x_i}\Big|_{x_i} = \hat{x}(K|K-1)$$
$$= \Big[\frac{\hat{x}_{k|K-1} - x_o}{r} \quad 0 \quad 0 \quad \frac{\hat{y}_{k|k-1} - y_o}{r}$$
$$0 \quad 0 \quad \frac{\hat{z}_{k|k-1} - z_o}{r} \quad 0 \quad 0\Big]$$

Ⅳ. ALGORITHM DISCUSSIONS

1. Adaptive filtering algorithm of acceleration mean

$$X(k)=\Phi(k|k-1)X(k-1)+u(k-1)\bar{a}+\omega(k)$$

$$\bar{a}_x=x(k+|k)=[0 \quad 0 \quad 1]X$$

Where

$$X=[x \quad \dot{x} \quad \ddot{x}]^T$$

So we get

$$\Phi(k|k-1)=\begin{bmatrix}[\Phi_1]' & & \\ & [\Phi_2]' & \\ & & [\Phi_3]'\end{bmatrix}$$

Where

$$[\Phi_i]'=\begin{bmatrix}1 & \tau_k & \tau_k^2/2 \\ 0 & 1 & \tau_k \\ 0 & 0 & 1\end{bmatrix}$$

$$\theta(k-1) = 2\alpha\sigma_m^2\left[\tau_k \quad \tau_k^4/8\right];\tau_k^3/6/\tau_k^4/8 \quad ;\tau_k^3/3 \quad ;\tau_k^2 /2/\tau_k^3/6;\tau_k^2/2 \quad ;\tau_k$$

Using the algorithm, the estimation of acceleration is taken as the mean of state noise.

2. Adaptive filtering algorithm of noise variance With the complexity of system random disturbance and target maneuvering, and also with the uncertain of model errors, the filtering caculation requires a pre–estimations of state noise variance Q and observing noise variance R. Through analyzing, the linear equation about Q is deduced as.

$$Y_{k+1}=H_{k+1}B_kQB_k^TH_{k+1}^T+\varepsilon_{k+1}$$

where ε_{k+1} is zero–mean random matrix.
If Q is a constant diagonal matrix, then the state equation is:

$$\hat{Q}_{k|k-1}=\hat{Q}_{k-1|k-1}$$

Observing equation is:

$$t_r(Y_{k+1})=t_r[H_{k+1}B_kB_k^TH_{k+1}^T]t_r(Q)+t_r(\varepsilon_{k+1})$$

We can use kalman filtering to get the estimation of Q(k).
If Q isn't a constant diagonal matrix, the other operator will be employed to establish the relevent observing equation.

3. U–D algorithm

Computer round–off errors can lead the covariance matrix P to become non–positive definite or non–symmetry in realizing the algorithms mentioned above. It causes the filtering gain and estimation to depart from the theoritical value more and more.

U–D fractorization algorithm is given by G.J. Bierman at first. Efficient updating recursions are executed by the unit upper triangular matrix U and the diagonal matrix D. Matrix P is being semi–definite by reformulating the recursions of matrix P to recursions of matrices U and D.
With a scalar measurement of one dimention

$$y=a^TX+v$$

State covariance is given by kalman filtering equations

$$P_{k|k}=P_{k|k-1}-K_ka^TP_{k|k-1}$$

Where

$$K_k=P_{k|k-1}a/\alpha \qquad \alpha=a^Tpa+r$$

r is observing noise variance

$$\begin{aligned}P_{k|k}&=P_{k|k-1}-P_{k|k}\cdot a\cdot\frac{1}{\alpha}\cdot a^T\cdot P_{k|k-1}\\&=u_{k|-1}[D_{k|k-1}\\&\quad-D_{k|k-1}u_{k|k-1}^Ta\cdot\frac{1}{\alpha}\cdot a^T\cdot u_{k|k-1}\cdot D_{k|k-1}]u_{k|k-1}^T\end{aligned}$$

$$P_{k|k-1}=u_{k|k-1}D_{k|k-1}u_{k|k-1}^T$$

Make

$$\begin{aligned}V_k&=D_{k|k-1}\\&\quad-D_{k|k-1}u_{k|k-1}^T\cdot a\cdot\frac{1}{\alpha}\cdot a^T\cdot u_{k|k-1}\cdot D_{k|k-1}\end{aligned}$$

and suppose $V_k$could be decomposited into

$$V_k=\bar{u}_k\bar{D}_k\bar{u}_k^T$$

Then:

$$\begin{aligned}P_{k|k}&=u_{k|k-1}V_ku_{k|k-1}^T\\&=(u_{k|k-1}\bar{u}_k)\bar{D}_k(u_{k|k-1}\bar{u}_k)^T\\&=\hat{u}_{k|k}\hat{D}_{k|k}\hat{u}_{k|k}^T\end{aligned}$$

The next $\hat{u}_{k|k}$ and $\hat{D}_{k|k}$ is:

$$\hat{u}_{k|k}=\hat{u}_{k|k-1}\bar{u}_k \ , \quad \hat{D}_{k|k}=\bar{D}_k$$

The state update is decided by the U–D fractorization factor of Vk.

Extending to vector measurement case, the measurement should be normalized so that the coveriance matrix of measurement noise R is diagonal, otherwise cholesky decomposition should be adopted.

V. COMPUTER SIMULATIONS

In simulation study, initial value is acquired by taking the initial location as a fixing point and using the fixing point positioning algorithm (direct linearization to non–linead models). Figure 3 gives the comparison of adaptive acceleration mean method and non–adaptive method. The algorithm is simple and has little modification about model. When the model random disturbance is not heavy and the model is exactly known, the good estimate accuracy can be obtained.

Figure 4 is a demonstration of adaptive filtering error estimation using noise variance estimate algorithm. The method has a good accuracy, but long computation time for parameters pre–estimating. If sampling frequency is too high it is difficult to process in real time.

U–D fractorization algorithm break up the recursion mode of conventional kalman filtering and prevent the filtering from unstability which is caused by round off errors. It is well suited for real time processing for its numerically stability and less storage in computer than general kalman measurement update algorithm. Figure 5 and Figure 6 are the comparison of U–D algorithm and non–U–D algorithm of the mentioned methods. There is a distinct improvement in positioning accuracy by U–D fractorization algorithm.

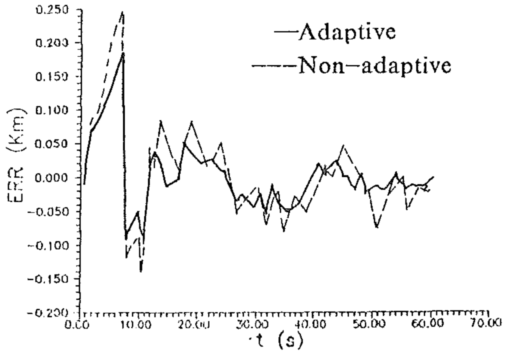

Figure 3 Adaptive filtering of acceleration mean

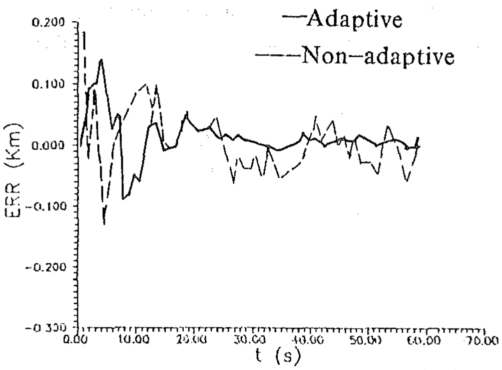

Figure 4 Adaptive filtering of noise variance

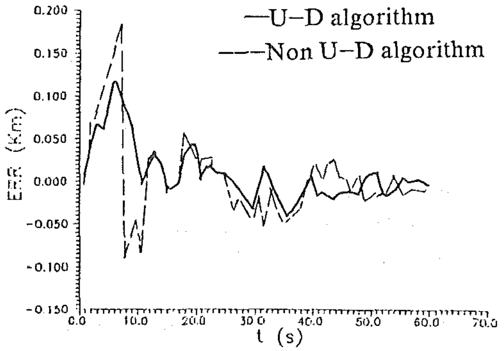

Figure 5 U–D fractorization algorithm in adaptive filtering of acceleration mean

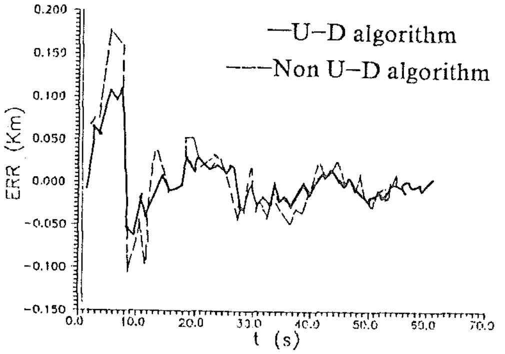

Figure 6 U–D fractorization algorithm in adaptive filtering of noise variance

VI. CONCLUSIONS

The scheme of satellite–based integrated positioning and communication system is elaborated in the paper. Exellent results on positioning accuracy and stability indicate that the utilization of various improved kalman filter algorithms is successful. The system is a new information system which gathers many new technologies, such as satelof the computer technology, the new generation of telemetry computer systems is high under the way. It can be fairly safe to say that with the availability

of faster computers and more sophisticated software, the performance of PCM will further be improved. To illustrate the tend, the following two figures are cited:

Responding to the need for higher data rates,manufacturers are offerring PCM ground stations at higher bits rates than ever before. The EMR 8300 series equipment from Fairchild Weston Systems,Inc., for example, offers bit synchronization to 33 megabits per second and end-to-end operation to 20 megabits per second.

The latest PCM ground station devices feature internal microprocessors, which enables the designer to offer command translation, self-diagnostics,and other features never before available.

C. Introduction of data randomizer and derandomizer

— There has always been a problem to deal with strings of 0's and 1's in the data stream, i. e. if there is a succession of 0's and 1's, the bit synchronization will fail and therefore such case is not allowed. Fortunately, a new technique has been adopted to overcome this problem, the diagram of which is shown in Fig.3 as follows.

D. The explicit proposition of idea "Success through telemetry"

Since telemetry has been incorporated into the field of armament (such as aeroplanes, missiles, satellites, etc)as well as communication, more and more people begin to feel that without the help of telemetry systems, there would not be any true success in most fields in the current society.

II.Status of telemetry inside China

Before the open-to-the-outside-world policy was introduced, telemetry systems began to developed in China as early as 1958 independently.Now,with the efforts of all Chinese researchers, the gap between the newest technology in the advanced countries and that in China has been reduced and further developments can be expected in the near future. In the descriptions below, the research activities at the author's lab are emphasized.

A. General status and history of telemetry.

In 1958, the Chinese Acadamy of Sciences developed a 4 channel FM system Later, a optical-electronical institute developed a 6 channel FM system. Still later, a mechanical institute made further improvements.

The research group at the Electronic Engineering Department of Beijing University of Aeronautics & Astronautics (BUAA) have been developing telemetry system all the time since early 1980s. We have developed a series of laboratory prototypes in these years:12 channel PBW FM system(1982) , 23 channel PBW FM system (1984), PBW-24+CBW-B (1985), CBW-F, G(1986). Some of these models have been put into real use by several factories. Now we can fulfill all the use Criteria stated in the IRIG standard 106-86.

B. A major step forward in PCMtechnique

Being the main stream of telemetry system, our research group at BUAA have plunged a large part of our effort into the study of PCM. Up to last year (1991) several key known-hows have been solved which include:

(1)Bit synchronizer

The telemetry bit synchronizer is typically a very flexible unit. It can accomodate a number of differing PCM codes, and can be optimized of performance in a variety of noise environments. In our lab, some synchronizer with bit rates ranging from 100bps to 4Mbps have been made. They are almost, if not absolutely, the best laboratory models in China.

(2)Frame synchronizer

The frame synchronizer adopts fixed

stategy. It is based upon separating the synchronization into three distinct operating modes:search,check and lock. Once minor frame synchronization is established, syn chronization of subcommutated channels can be accomplished. Any PCM format with varying synchronization patterns can now be made up to 5Mbps, here in BUAA.

(3)PCM data simulator

A valuable addition to a telemetry system is a programmable simulator,which generate a PCM output for . system checkout. It is available also as one of the outputs to the bit synchronizer. Bit rates up to 5Mbps are now realized by us

(4)Data preprocesser

Telemetry data rates are increasing rapidly. The number of analysts per system is increasing, as are their data display requirements. Even though minicomputers are large and faster than ever before,they have not kept pace with the demands of telemetry users. In our experiments,the DSP chip TMS320C25 is used to construct successfully a preprocessor with similar function of EMR 8571.

Now, a 6.5Mbps PCM telemetry system is available as a laboratory model.

C. The new telemetry system--SDM

Based on the traditional theory of orthogonal multiplex,the two telemetry systems FDM and TDM have long been advanced. Many people tend to think that they are the only two systems based on orthogonal functions. However, in 1980, we proposed a third one--sequency division multiplex(SDM) based on Walsh functions which are also orthogonal and complete.Since then, we continued to study SDM system and a new one basedon Haar function was introduced in 1983.

In 1982, we discovered another new kind of orthogonal function called Bridge functions which can link a series of orthogonal functions such as Walsh, Haar, block, etc. like a bridge (that's why it is so named),the Bridge functions have the every promise of being the basis for constructing another SDM system which was fulfilled and named as BAM-FM in 1990.

Conclusion

In all, telemetry systems both inside and outside China have been well advanced in these years. Surely, they will play a much more important role in the future developments.

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TELEMETRY DATA RATE TRENDS

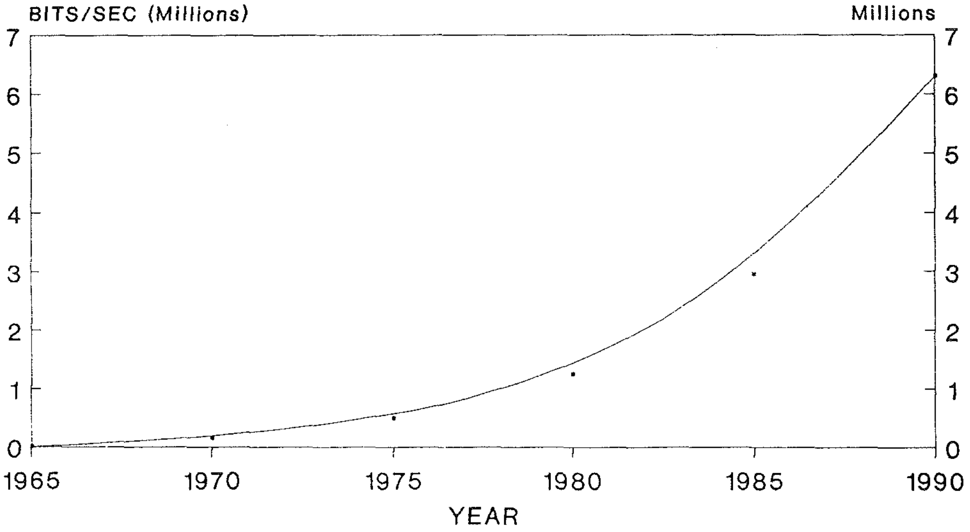


Figure 1.

TELEMETRY SAMPLE RATE TRENDS

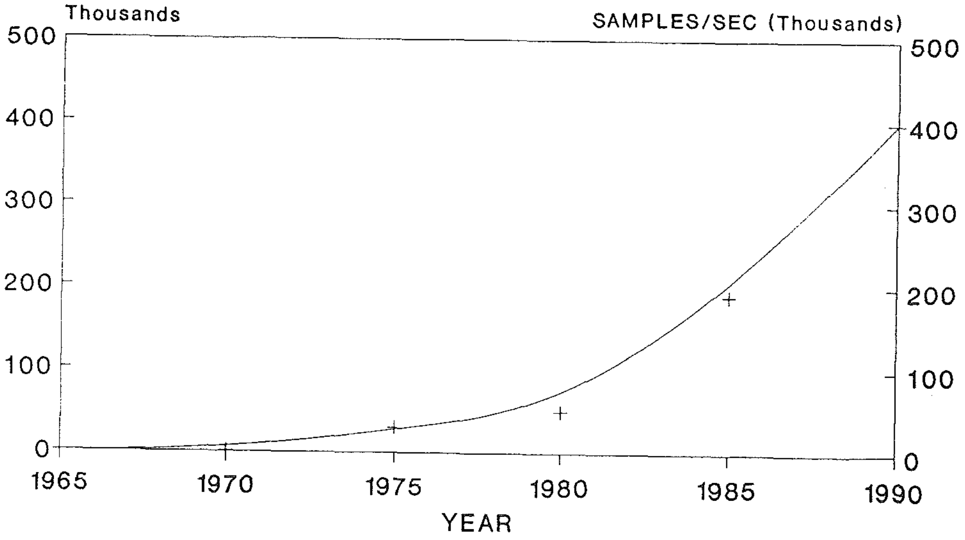
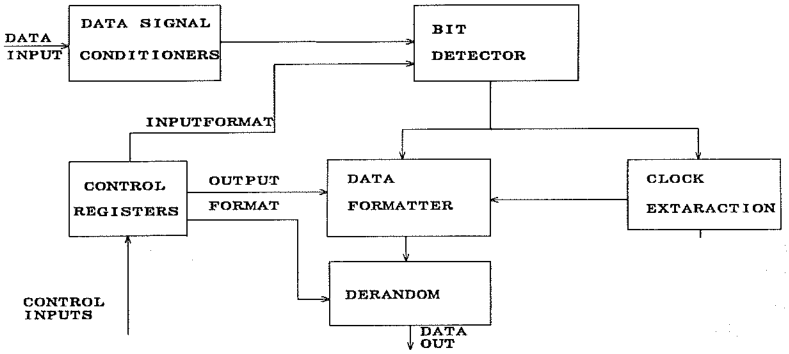


Figure 2.


DATA INPUT
DATA SIGNAL CONDITIONERS
BIT DETECTOR
INPUTFORMAT
CONTROL REGISTERS
OUTPUT FORMAT
DATA FORMATTER
CLOCK EXTARACTION
DERANDOM
CONTROL INPUTS
DATA OUT