LASER RANGE FINDING BASED ON CORRELATION METHOD

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Abstract: The purpose of the paper is to present a new laser diode range finding method. The system belongs to the category of flight time measurement. The optical power of the laser diode beam is modulated and then both emitted and returned signals are compared in order to obtain the delay or distance information.

The new method is an estimation of the distance by correlation computation. The main advantages of this method are presented by simulation studies showing the robustness of the method towards noise and coupling phenomena.

Then a prototype is presented associating the optical head and a simple RF board producing the signal modulating the laser beam. This signal is itself frequency modulated by a sine wave. The sampling process is performed by a digital scope and correlation computation is performed by a PC computer.

The main application concerns indoor robotics.

Keywords: laser diode, frequency modulation, high frequency sampling, correlation

1 INTRODUCTION

Laser range finders make the most of the fundamental properties of coherence and of directivity. They have been widely studied in the world of research, and many measurement methods have been developed for distance estimation [1-2]. The principle can be based on a geometrical effect, on a propagation time or on interference phenomenon. Some of the systems use an optical power modulation and for this kind of technique the laser diode is the best suited because of the easy forward current modulation. Nevertheless the reputation of laser based metrology systems is to be expensive and fragile. It is mainly the case of systems based on interferometry ; they are very powerful in term of resolution and accuracy but not in term of range which is limited by the coherence of light. Depending on the application it is not always necessary to have a very high resolution. In case of indoor robotics a resolution of one centimeter is enough but some times for a wide range such as ten meters or more.

2 OVERVIEW OF LASER RANGE FINDING TECHNIQUES

We present here some methods leading to the introduction of our new correlation system.

2.1 The classical techniques

Laser range finding techniques always refer to a physical effect between an emitted signal and a received signal. Triangulation method corresponds to the case of geometrical effects and is widely used in different kind of industrial applications. The range covers some centimeters to some meters and the resolution can be less than 1 μm [3].

The time of fight category concerns range finders for which the distance d to be measured is obtained from the propagation time τ_d of the optical wave reflected by the target. With the light velocity c then :

$$\tau_d = \frac{2d}{c} \tag{1}$$

The optical power of the laser beam is modulated and then both emitted and returned signals are compared in order to obtain the delay or distance information. Whatever the measurement method there is a common part, the optical head producing the incident optical beam from an electronic test signal and converting the reflected beam into a received electronic signal. The optical head is presented Figure 1. The design leads to an unique optical axis.

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If the optical power is modulated by a pulse then the fight time can be directly measured. If the optical power is modulated by a sine wave, at the frequency f_0, then the propagation time is converted into a phase-shift $\Delta\varphi = 2\pi f_0 \tau_d$ between the emitted and returned signals.
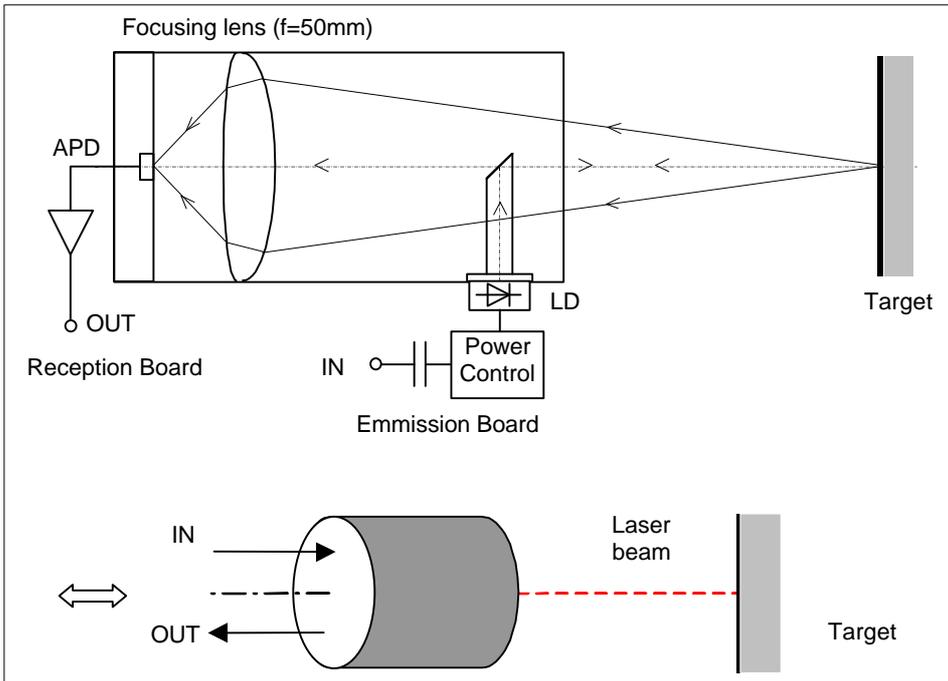

Figure 1.   Block diagram of the optical head

2.2 The FMCW-like method

A way to improve the resolution of measurement systems is to use wide band modulation giving more information [4]. A first possibility is to modulate the optical power of the laser beam by a saw tooth signal. In this case the time of flight τ_d is converted into a beat frequency. This method corresponds to the usual FMCW method developed for radar but here it is the optical power that is modulated and not the optical carrier frequency, thus the name FMCW-like. Such a method has already been presented with interesting results but with rather complex and costly systems [5].

The phase delay $\Delta\varphi(t)$ of the returned signal with respect to the emitted signal depends on the instantaneous frequency $f_e(t)$ of the emitted signal, on the flight time τ_d, but also on the electronic delay $\phi_E(t)$ introduced by the electronic devices of the optical head.

$$\Delta\varphi(t) = \left(2\pi f(t)\tau_d\right) + \phi_E(t) \qquad\qquad (2)$$
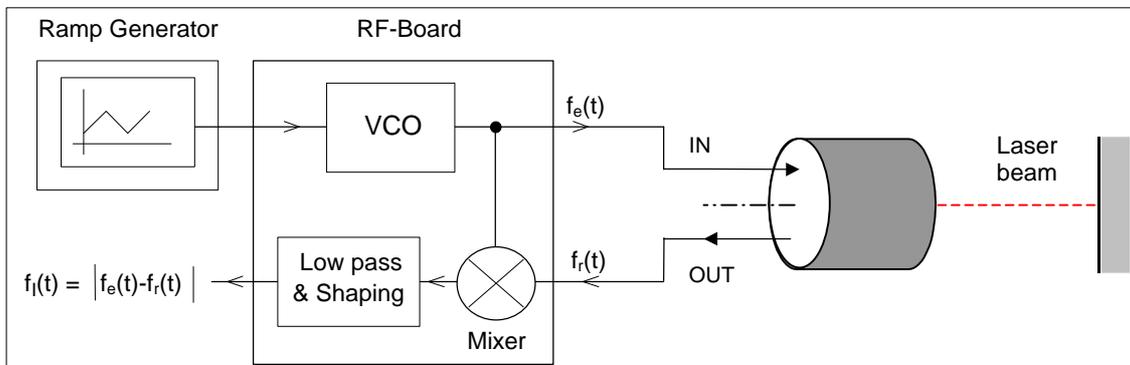

Figure 2.   Block diagram of the FMCW like range finder

The phase shift $\Delta\varphi$ is obtained by mixing both emitted and received signals and the corresponding instant frequency is $f_I(t)$ given by the next formula where T_R is the period of the ramp command and Δf the span of the VCO [6].

$$f_I(t) = \frac{1}{2\boldsymbol{p}} \cdot \frac{d\Delta\boldsymbol{j}\,(t)}{dt} \approx \frac{2\Delta f}{T_R}\frac{2d}{c} \tag{3}$$

This method is rather simple and leads to a low cost system. But the main drawback concerns the VCO non linearity. The RF VCO employed here is working on a large span compared with the centre frequency and RF VCO's are not conceived for such applications. And of course this non linear behaviour affects the accuracy of the measurement.

3   THE CORRELATION METHOD

Two kinds of solutions are conceivable to solve this linearity problem. The first one is a dynamic linearization of the VCO and the second one is the taking into account of the whole signal aspect.

The first solution has already been studied for FMCW radar [7] but it is very complex and expensive. The second one could be a study of the "resemblance" between the emitted signal and the received signal. This resemblance reaches its maximum value at the time corresponding to the time of flight of the laser beam. In other words we have described the calculation of the correlation between the emitted and received signals.

3.1 Description of the system

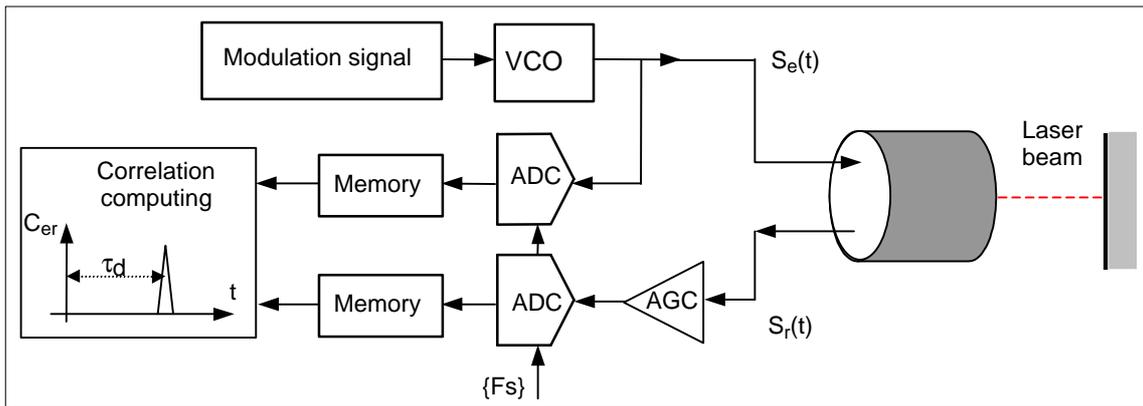According to the previous presentation the principle of the apparatus is shown at Figure 3.

Figure 3.   Organization of the laser range finder based on correlation method

The main parameters for such a system are:
- the sampling frequency (F_S).
- the number of sample points (N_P)
- the number of quantification bit (N_Q).

An important point is that a linear modulation of the VCO is not required (in order to show that our system solves the linearity problem previously mentionned). We choose a sine wave modulation.

The choice of F_S is fixed by technological consideration. The actual techniques are limited by sampling frequency of around 10 GHz with 8 bits quantification. It is possible to find now scopes or PC acquisition boards digitizing up to 1 or 2 GHz. So we have chosen $F_S = 1$ GHz, but we have considered only 6 bits quantification because the usual 8 bits are never really significant.

The trip time of the laser beam gives a distance of 15 cm per nanoseconds ($d = c.\tau_d / 2$). If we admit that we can find the maximum correlation with a tolerance of one sample we obtain a resolution for measurement proportional to the sampling period (T_S). If $F_S = 1 / T_S = 1$ GHz, the resolution should be 15 cm. We notice that the accuracy of the measurement remains constant over the whole distance range (apart from the problem of the attenuation of the received signal).

The number of memorized points has different influences on the measurement. The first one concerns the quality of the result obtained when calculating correlation because the longer is the signal, the higher is its energy and more optimised is the computing of correlation). The second one is the maximum distance that can be measured. Indeed, if the number of points is not sufficient, the

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reflected signal arrives after the end of the acquisition process. During simulation Np = 8000 appears a good compromise to obtain a satisfying result on the first criterion and leading to a range up to 1 km.

3.2 Simulation results

The choice of modulation signal parameters is based on the component available at our laboratory. The VCO is an HV-17-T1 from Magnum Microwave Company, with a 50 to 100 MHz range. A first experiment has shown that it is possible to use a sine wave at 150 kHz for the modulation signal, leading to a center frequency of 62.5 MHz and a span of 25 MHz for the RF signal.

We construct a digitized frequency modulated signal $S_e(kT_s)$. This signal is then delayed and white noise is added giving a digitized received signal $S_r(k'T_s)$. Then we calculate the correlation between the emitted signal and the received signal. The computing formula is reminded.

$$C_{er}(m.T_s) = \frac{1}{Np+1}\sum_{k=0}^{Np} S_e(k.T_s).S_r((k-m).T_s] \tag{4}$$

The simulations were performed with MATLAB™ software. We have studied the influence of the different parameters F_S, N_P, N_Q, an additive noise to the emitted and the received signals, the existence of a coupling between emitted and received signals.

The first result on Figure 4. corresponds to the correlation computation. The emitted signal has a r.m.s. value of 0.707V and is polluted with white noise of 0.5Vrms corresponding to $SNR_E=1.41$. The received signal is time delayed from 666 ns. A white noise of 5Vrms is added to the received signal which is also of 0.707Vrms leading to $SNR_R=0.141$.
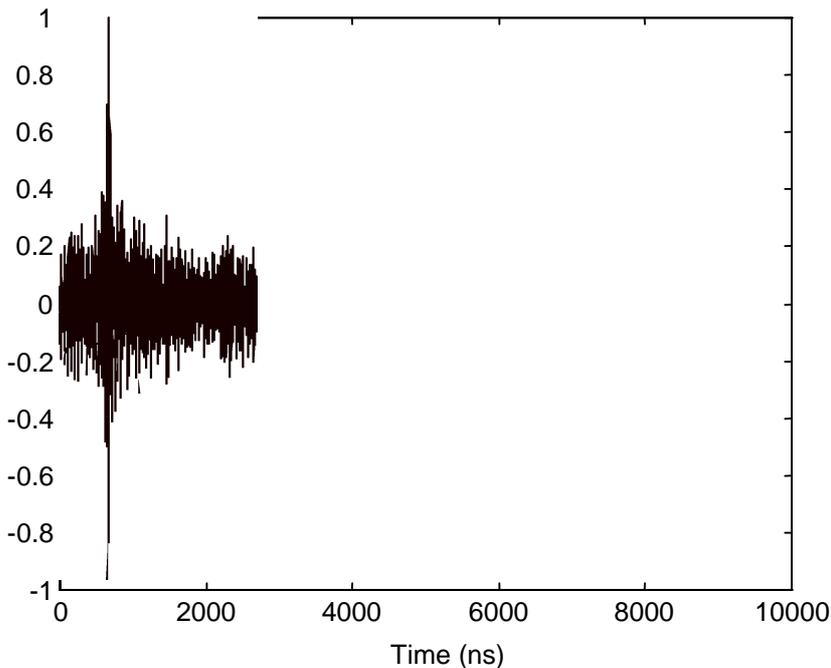

Figure 4.   Correlation result in case of noisy emitted and received signals

The robustness of the apparatus to the addition of non-correlated noise to the emitted and the received signals is very encouraging. We find here the capabiliity of the correlation to extract useful information. This can be compared with the GPS (Global Positioning System) [8] and to the spread spectrum modulation [9] where similar results are found. The extraction of the useful information is done while signal level is below the noise level.

The results obtained with 6 bits quantification are also encouraging. The time of flight is very clear on the figure 4 and we have also obtained good results with only 4 bits quantification. That is because the correlation has a similar sensitivity concerning the increase of noise and the decrease of the number of quantification bits. We have to make a compromise between the number of digitized points, the noise levels, and the number of quantification bits to conserve good results.

The second simulation corresponds to the same signals but with an important coupling phenomena from the emitted signal to the received signal. For this simulation 90% of the emitted signal is injected

to the received signal which is a very high rate. Results are presented on the Figure 5. In case of "a phase-shift laser range finder" such a coupling phenomena leads to a phase error of about 50%. But we can see that in case of the "correlation laser range finder" the coupling is quite no more a problem. The coupling produces a correlation component very near the origin and a simple software processing can eliminate this effect; the position of the time of flight is not affected by this coupling. In practice, we will have to make sure that the coupling does not saturate the reception stage.
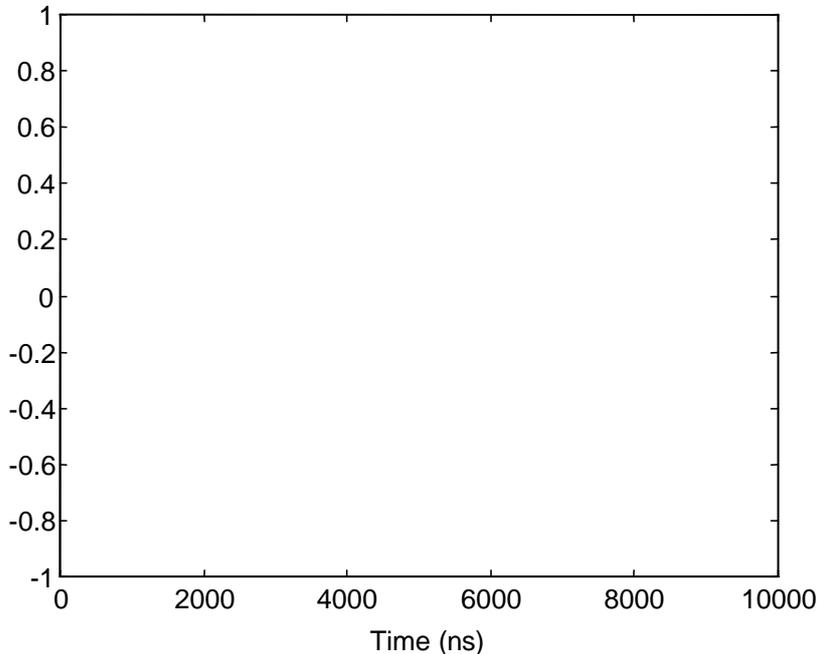

Figure 5.   Correlation signal obtained with 90% coupling rate.

3.3 Time of flight detection

The time of flight is detected as the instant corresponding to the maximum of the correlation result. In this method there is no conversion of the physical quantity time into an other quantity as a phase-shift or as a beat frequency. The method is thus in this way similar to the pulse method. The instant to be detected is also small, but much more energy is sent and so the accuracy should be better. Compression techniques should be developed in this case to improve the resolution limited by the sampling frequency.

4   EXPERIMENTAL PROCESS

We describe in this part the experimental set-up that we are building.

4.1 Optical head characterization

As it is a fundamental part of the measurement system the optical head has to be fully calibrated. It can be considered by including the emission board, the reception board, the optical path and the target as an electro-optical quadripole. A vector analyzer is used to perform the calibration process [6].

4.2 Description of the experiment

A feasibility experiment is currently being developed to validate the conception of our system. The digitizing and the memorization stages are realised with a digital scope HP54510A (F_S = 1 GHz, N_P = 8000, N_Q = 8). The output signal of the VCO can be analyzed with a time domain analyzer like HP53310A, showing the capability of the VCO to respond to a 150 kHz sine wave. The PC is running under Microsoft Windows NT 4.0, and the whole control software is written in Borland C++ Builder.

Of course as we don't know the distance to be measured the sampling process must starts at the same time for both signals, that is a very important point. We choose to digitise both emitted and received signals to facilitate the quality of the result. Later on it should be possible to acquire only the received signal and to compute the correlation with an image of the emitted signal which as been memorized.

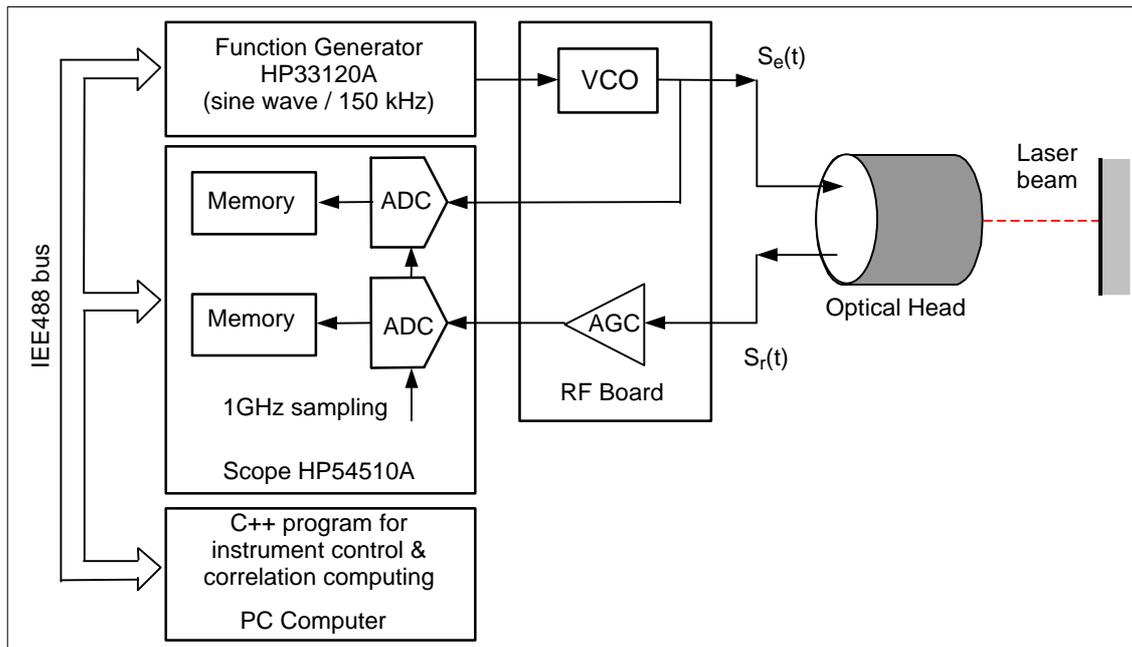The experimental set-up is presented on Figure 6.

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Figure 6. Block diagram of the feasibility experiment

5 CONCLUSION

The simulations conducted show the main advantage of this method that is its robustness towards noise, coupling phenomena, and towards quantifiication. An experiment is being developped in order to prove the feasibility of the method. At this state of the work it is difficult to estimate the price of such a system, but because of the high rate sampling that is required it should not be very low-cost until price of this kind of ADC are not going down, but as for other electronic devices things can change very fast and very dramatically. This method needs of course further development.

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