Methods and algorithms for the error correction of odometers in the recognition pipeline system "PIG"

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Abstract. To carry out a correct mapping or location of flaws in pipelines that transport hydrocarbons it is necessary to have a system that carries out the distance measurement with a percentage of minimum error, being the odometer the element essentially used for this task, the present article it details three methods that maintain the error percentage below the wanted values.

1. - Introduction.

In the oil industry the area of transport of hydrocarbons is essential, for example, for PEMEX (Petróleos Mexicanos) the leakage, secret takings or bumps in the ducts are able to cause bigger losses to the 18 million annual us dollar [1], besides putting in danger to the communities and the environment, where they are carried out this illicit or physical damages.
Given the previous information the oil industries need a periodical inspection of the several thousands of kilometers of pipelines with those they count on, they are forced to produce the inspection service and exploration of pipelines to a limited number of companies in the environmental world that handles these services, generating an expenditure of approximately 5,000.00 us dollars per kilometer.

An inspection and exploration system of pipelines that is known internationally as "PIG" it has either mechanics, magnetic or ultrasonic sensors, with which is known the state in which the ducts are found and if the PIG has a Inertial Navigation System (INS) and odometers are able to carry out the corresponding mapping.
If it is required to know with accuracy the location of the pipe as well as their flaws, it is indispensable to have an efficient system for the measurement of distances.
There are different systems like Dopler, Inertial and the more used in the PIG in spite of having errors of 0.5% wish per kilometer [2] the odometers, for that that the calibration of this element as well as the implementation of methods and algorithms that help to the reduction of the error generated by these devices are priority.

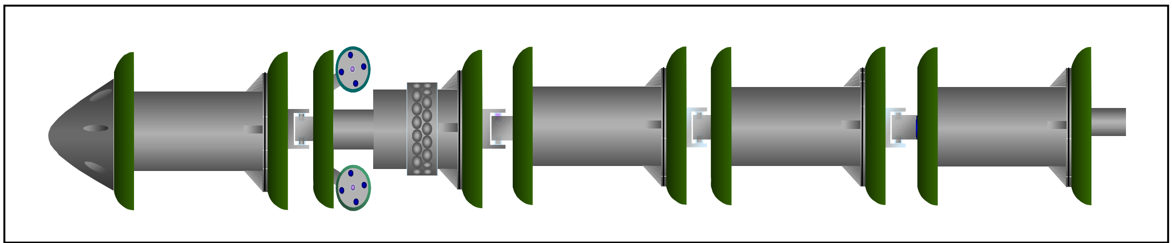

Fig 1. PIG linked INS tools and odometer.

2. - Problem Formulation.

The conditions to which the PIG undergoes are standard in the transportation of hydrocarbons that are pressures until of 120Kg/cm2, temperatures until of 50°C and speed of up to 2m/s.

The PIG is shown in the figures 1. It is an element that has diverse tools linked to INS and odometers that allow to know the location and the such defects when traveling the pipelines internally like: the lost of metal, corrosion, ovalamientos, bumps, corrugations and leakage.

The INS and the odometers, provide as much the trajectory as the distance traveled by the tool from the starting point until the location of the flaws or the time that the race lasts, because of that the calibration and synchronization of both systems are essential so that the generated data are reliable.

Considering the error wish of 0.5% per kilometer, one has when carrying out distance measurement with odometers, in tests of 100Km deviations go up to 500m, because of that the price for the location, maintenance and repair of the pipelines is high.

3. - Problem Solution

Methods exist to minimize the error caused by the odometers, for example placing reference points (like they can be points GPS Global Positioning System) on the pipeline, in which elements are placed that detect the time in which the PIG goes for those points, making a correction of data for each placed point.

Three significant points exist to reduce the degree of provoked error for the odometers in the distance measurement traveled by the PIG, and they are: The odometers calibration, correction of data using the sensors mounted in the INS, as well as the welding sensors, by means of algorithms that correlate the obtained data and carry out adjustments systematically.

3.1 Odometers Calibration.

To carry out an appropriate calibration of the odometers the simulator was designed shown in the figure 2, it has an optic sensor to provide the number of turns of the base, mechanical support of adjustable pressure, a magnetic

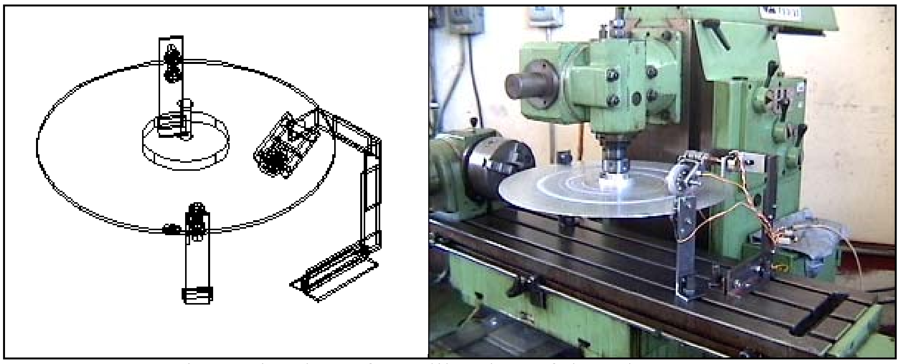

Fig.2. Simulator for calibration of the odometers.

Table 1. Concentrated of data of odometers calibration.				
	Odometer 1	**Odometer 2**	**Odometer 3**	**Odometer 4**
Time (s):	600.38	600.05	600.62	600.42
Number of Turns (optic):	496	495	495	496
Number of pulses (odometer):	26345	24847	25294	24566
Optic factor (m):	1.0442	1.0358	1.0134	1.0134
Factor of Odometer (m):	0.0197	0.0206	0.0198	0.0205
Real Distance (m):	517.9232	512.7210	501.6330	502.6464
Traveled Distances (m):	518.9965	511.8482	500.8212	503.6030
Distance error (m):	-1.0733	0.8728	0.8118	-0.9566
Percentage of Error:	**-0.2072%**	**0.1702%**	**0.1618%**	**-0.1903%**

Table 2. Pulses of the odometer with different dimensions of weldings					
Weldings (Wide*Height)		4mm*2mm	4mm*8mm	10mm*2mm	10mm*8mm
Odometer 1	without welding 26345	26292	26275	26262	26248
Odometer 2	without welding 24847	24798	24913	24770	24754
Odometer 3	without welding 25294	25249	25360	25213	25199
Odometer 4	without welding 24566	24519	24630	24491	24475

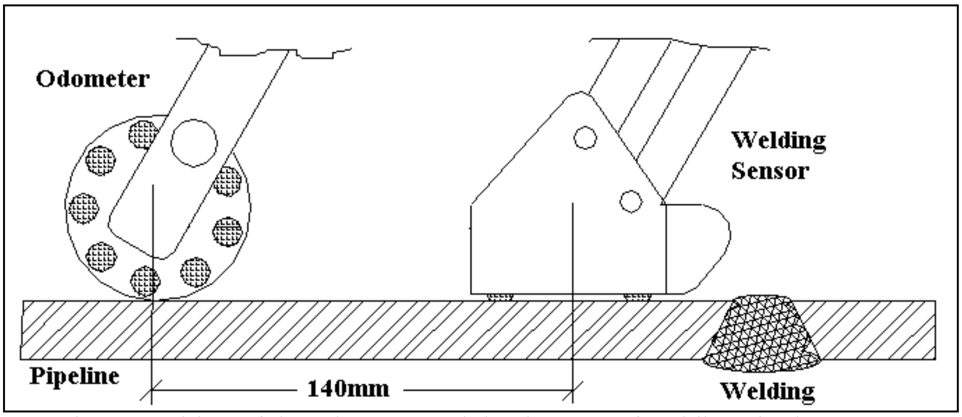

Fig. 3. Position of the odometer and the detector of weldings in the PIG.

sensor to count the number of pulses provided by the odometer, interchangeable pieces that simulate the step of the odometers for weldings and a potentiometer that measures the step for weldings.

With this simulator they were carried out tests to different speeds with different intervals of time for each one of the odometers mounted in the PIG having the results shown in the table 1, where it's observe that the percentage of provoked error for the calculated coefficient is smaller than ±0.3%.

When adding probable conditions of error like it is the step of the odometer for weldings one has an increase from the error to ±0.9%, this increment was compensated using the principle described in the following section.

3.2 Correlation algorithm between the welding sensors and the odometers.

Since it has gauged the odometer, we know with accuracy the distance that travels for pulse, every time that passes for a welding the odometer jumps making that this it loses the reading of 1 pulse each 7 to 13 weldings, depending on the speed to which it moves the PIG and the type of feigned welding.

Of specifications all the weldings should be as the one that is shown in the figure 3, with a certain wide and height; but carrying out an inspection in diverse pipelines you verify that different wideness that go from 4mm to 10mm with a height between 2mm and 8mm exist. The results in the table 2 are shown for each one of the possible combinations between wideness and height to different speeds.

The pipe tracts have a estimated distance among 8 to 12 meters, estimating that for each tract it passed a welding at least if it is that doesn't have additions, coples or flanges; nevertheless making use of the welding sensors that are at 140mm of the odometers just as it is shown in the figure 3. the number of existent weldings is counted in the pipe generating a correction of 1 pulse for each 9 welding.

3.3. Correlation algorithm between the inertial sensor and the odometers.

Taking in consideration the elementary mechanization of a strapdown system [3], it is observed how it is carried out the process of conversion of the readings from the sensors to quantities that reflect the specific movement in each axis inertial orthogonal referred to the body.

Once the conversion was made and to carry out a synchronization with the vector time the speed average is determined by means of the equation 1.

$$\bar{v} = \frac{\sum_{k=1}^{n} \frac{\overline{\Delta p_k}}{\overline{\Delta t_k}}}{n-1} \cdots\cdots\cdots ec.1.$$

$$\begin{aligned} Where: \quad \Delta p_1 &= P_1 - P_0 \\ \Delta p_2 &= P_2 - P_1 \\ &\vdots \\ \Delta p_n &= P_n - P_{n-1} \end{aligned}$$

where: P Position stored, Δp_k is the distance traveled *k*-esimas stored positions and Δt_k is the time between samples and n it is the total number of samples.

Knowing this vector of speed is possible select the factor that minimizes the error generated, taking in consideration the carried out tests of the odometer with the step of weldings to different speeds.

With the correction factors for detecting of welding and for the inertial sensors the error provoked for the odometer is smaller than 0.3%. It fits to point out that this factor has not yet been corrected by external reference points which will allow to obtain a smaller error.

4. - Conclusion.

Carrying out an appropriate calibration of the different odometers the error caused by them you can minimize until less than 0.5%. Taking in consideration the alternative systems of the PIG like the welding detectors and the INS can stay the error below 0.3% caused by the step of the odometer by weldings or defects of the pipe.

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