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DESIGN OF NEURAL NETWORK-BASED UNIVERSAL LINEARIZER

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Abstract

A comparative analysis of different Thermocouples temperature Vs output response is provided. Different linearizers with their nonlinearity are compared with the general response of thermocouples is also given for universality. A Neural Network based solution in the analogue and digital domains is proposed the analysis will help designers to choose this linearization technique best suited for a given application.

Keywords: Analog Sensors, Digital Sensors, linearization, Sensors, Neural Network, Transducers, Sensor Linearization. Universal Linearizer.

I. Introduction

Nonlinear signals must be linearized to get rid of the design complexity of the system. Different sensors are available in the industry for linearization of temperature vs emf. Each one of them deals with one single type of sensor and tries to linearize its output. Instead of a specific technique if measurement is taken to find symmetry between a nonlinear sensor with a known device that is already present in the linear domain, then the linearization process becomes much easier.

II. Thermocouple Nonlinearity

The following table (Table 1) shows the difference between output characteristics of thermocouple-type temperature sensors in Temperature vs Emf generation. This Chart shows the response data for different types of Thermocouples with their input and out. [XIV]

Table 1: Comparative Analysis between Temperature and Output Voltage of Different thermocouple Sensors

°C	0	1	2	3	4	5	6	7	8	9	10	°C
Thermoelectric Voltage in Millivolts												
-270	-6.458											-270
-260	-6.441	-6.444	-6.446	-6.448	-6.450	-6.452	-6.453	-6.455	-6.456	-6.457	-6.458	-260
-250	-6.404	-6.408	-6.413	-6.417	-6.421	-6.425	-6.429	-6.432	-6.435	-6.438	-6.441	-250
-240	-6.344	-6.351	-6.358	-6.364	-6.370	-6.377	-6.382	-6.388	-6.393	-6.399	-6.404	-240
-230	-6.262	-6.271	-6.280	-6.289	-6.297	-6.306	-6.314	-6.322	-6.329	-6.337	-6.344	-230
-220	-6.158	-6.170	-6.181	-6.192	-6.202	-6.213	-6.223	-6.233	-6.243	-6.252	-6.262	-220
-210	-6.035	-6.048	-6.061	-6.074	-6.087	-6.099	-6.111	-6.123	-6.135	-6.147	-6.158	-210
-200	-5.891	-5.907	-5.922	-5.936	-5.951	-5.965	-5.980	-5.994	-6.007	-6.021	-6.035	-200
-190	-5.730	-5.747	-5.763	-5.780	-5.797	-5.813	-5.829	-5.845	-5.861	-5.876	-5.891	-190
-180	-5.550	-5.569	-5.588	-5.606	-5.624	-5.642	-5.660	-5.678	-5.695	-5.713	-5.730	-180
-170	-5.354	-5.374	-5.395	-5.415	-5.435	-5.454	-5.474	-5.493	-5.512	-5.531	-5.550	-170
-160	-5.141	-5.163	-5.185	-5.207	-5.228	-5.250	-5.271	-5.292	-5.313	-5.333	-5.354	-160
-150	-4.913	-4.936	-4.960	-4.983	-5.006	-5.029	-5.052	-5.074	-5.097	-5.119	-5.141	-150
-140	-4.669	-4.694	-4.719	-4.744	-4.768	-4.793	-4.817	-4.841	-4.865	-4.889	-4.913	-140
-130	-4.411	-4.437	-4.463	-4.490	-4.516	-4.542	-4.567	-4.593	-4.618	-4.644	-4.669	-130
-120	-4.138	-4.166	-4.194	-4.221	-4.249	-4.276	-4.303	-4.330	-4.357	-4.384	-4.411	-120
-110	-3.852	-3.882	-3.911	-3.939	-3.968	-3.997	-4.025	-4.054	-4.082	-4.110	-4.138	-110
-100	-3.554	-3.584	-3.614	-3.645	-3.675	-3.705	-3.734	-3.764	-3.794	-3.823	-3.852	-100
-90	-3.243	-3.274	-3.306	-3.337	-3.368	-3.400	-3.431	-3.462	-3.492	-3.523	-3.554	-90
-80	-2.920	-2.953	-2.986	-3.018	-3.050	-3.083	-3.115	-3.147	-3.179	-3.211	-3.243	-80
-70	-2.587	-2.620	-2.654	-2.688	-2.721	-2.755	-2.788	-2.821	-2.854	-2.887	-2.920	-70
-60	-2.243	-2.278	-2.312	-2.347	-2.382	-2.416	-2.450	-2.485	-2.519	-2.553	-2.587	-60
-50	-1.889	-1.925	-1.961	-1.996	-2.032	-2.067	-2.103	-2.138	-2.173	-2.208	-2.243	-50
-40	-1.527	-1.564	-1.600	-1.637	-1.673	-1.709	-1.745	-1.782	-1.818	-1.854	-1.889	-40
-30	-1.156	-1.194	-1.231	-1.268	-1.305	-1.343	-1.380	-1.417	-1.453	-1.490	-1.527	-30
-20	-0.778	-0.816	-0.854	-0.892	-0.930	-0.968	-1.006	-1.043	-1.081	-1.119	-1.156	-20
-10	-0.392	-0.431	-0.470	-0.508	-0.547	-0.586	-0.624	-0.663	-0.701	-0.739	-0.778	-10
0	0.000	-0.039	-0.079	-0.118	-0.157	-0.197	-0.236	-0.275	-0.314	-0.353	-0.392	0
0	0.000	0.039	0.079	0.119	0.158	0.198	0.238	0.277	0.317	0.357	0.397	0
10	0.397	0.437	0.477	0.517	0.557	0.597	0.637	0.677	0.718	0.758	0.798	10
20	0.798	0.838	0.879	0.919	0.960	1.000	1.041	1.081	1.122	1.163	1.203	20
30	1.203	1.244	1.285	1.326	1.366	1.407	1.448	1.489	1.530	1.571	1.612	30
40	1.612	1.653	1.694	1.735	1.776	1.817	1.858	1.899	1.941	1.982	2.023	40

50	2.023	2.064	2.106	2.147	2.188	2.230	2.271	2.312	2.354	2.395	2.436	50
60	2.436	2.478	2.519	2.561	2.602	2.644	2.685	2.727	2.768	2.810	2.851	60
70	2.851	2.893	2.934	2.976	3.017	3.059	3.100	3.142	3.184	3.225	3.267	70
80	3.267	3.308	3.350	3.391	3.433	3.474	3.516	3.557	3.599	3.640	3.682	80
90	3.682	3.723	3.765	3.806	3.848	3.889	3.931	3.972	4.013	4.055	4.096	90
100	4.096	4.138	4.179	4.220	4.262	4.303	4.344	4.385	4.427	4.468	4.509	100
110	4.509	4.550	4.591	4.633	4.674	4.715	4.756	4.797	4.838	4.879	4.920	110
120	4.920	4.961	5.002	5.043	5.084	5.124	5.165	5.206	5.247	5.288	5.328	120
130	5.328	5.369	5.410	5.450	5.491	5.532	5.572	5.613	5.653	5.694	5.735	130
140	5.735	5.775	5.815	5.856	5.896	5.937	5.977	6.017	6.058	6.098	6.138	140
150	6.138	6.179	6.219	6.259	6.299	6.339	6.380	6.420	6.460	6.500	6.540	150
160	6.540	6.580	6.620	6.660	6.701	6.741	6.781	6.821	6.861	6.901	6.941	160
170	6.941	6.981	7.021	7.060	7.100	7.140	7.180	7.220	7.260	7.300	7.340	170
180	7.340	7.380	7.420	7.460	7.500	7.540	7.579	7.619	7.659	7.699	7.739	180
190	7.739	7.779	7.819	7.859	7.899	7.939	7.979	8.019	8.059	8.099	8.138	190

III. Linearization Process

Characteristic of most sensors is nonlinear in nature [V, XV], obtaining data from a nonlinear sensor by using a normal digital device has always been a design challenge [VII]. Analogue sensors have always been better at getting the response from the measuring entity [VIII]. Digital Sensors always provide better linearity but lack continuity of data when processing. It is undoubtedly clear that for better sensors Analog models are the best [XII]. Unfortunately, each one shows its version of non-linearity with its characteristics. As a result, a major task becomes to convert that nonlinearity into linearity. Each one of the sensor characteristics must be linearized to get an Ultimate Universal linearizer which can linearize any nonlinear response from any of the sensors available Analog linearization techniques are in general the simpler ones and can have a low cost in terms of silicon area and power consumption. Their main drawbacks are sensitivity to environmental conditions (mainly temperature), lack of flexibility when a different kind of sensor is employed, and that accuracy is high typically only in a small input range [VI]. Hence, they are usually the preferred choice in low-cost, low-performance applications where the linearized output is required in analogue form.

The following chart shows the difference in output response of different types of Thermocouples (Fig 1) [I]. As the chart shows starting from 00 C to 1000 C the non-linearity ratio is less in comparison to the higher temperature. To use different types of Thermocouples in a single system its essential that every sensor output must be linearized to a single linear curve.

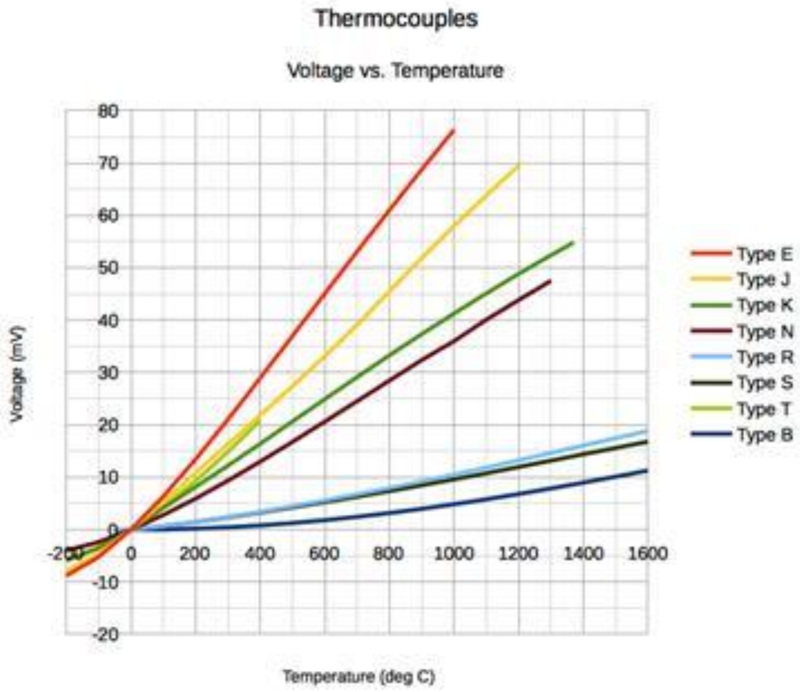

Fig 1. Thermocouple: Temperature VS Output for each and every type

The following chart (Table II) shows the usage details and specifications of different types of Thermocouples. As the chart shows [V, XV] Type K, N, R, S, B are much more expandable in the temperature range in comparison with the Type E, J, T. [XVI] Whereas for continuous use Type R and S [II] shows the best results, however, nonlinearity portion is also very high for the upper-temperature range.

Table 2: Comparative Analysis between different types of Thermocouples

Type	Short Term Use	Continious Use	Class 1 Tolerance	Class 2 Tolerance	Class 3 Tolerance
Type E	-40 to +900	0 to 800	-40 to 800	-40 to 900	-200 to 40
Type J	-180 to +800	0 to 750	-40 to 750	-40 to 750	NA
Type K	-180 to 1300	0 to 1100	-40 to 1000	-40 to 1200	-200 to 40
Type N	-270 to 1300	0 to 1100	-40 to 1000	-40 to 1000	-200 to 40
Type R	-50 to 1700	0 to 1600	0 to 1600	0 to 1600	NA
Type S	-50 to 1750	0 to 1600	0 to 1600	0 to 1600	NA
Type T	-250 to +400	-40 to 350	-40 to 350	-40 to 350	-200 to 40
Type B	0 to 1820	200 to 1700	NA	+600 to +1700	+600 to 1700

- All Temperatures are at ^{0}C

IV. Linearization Process

The following Figure shows the differences in specifications between all the different types of temperature sensors [III]. Specification wise Thermocouples are mostly used for long expansions of temperatures. Compared to the thermocouple RTD [XIII], Thermistor [IX] or Semiconduction Diodes [IV] proved a response for a small range of Temperatures. Whereas linearity wise Semiconductor IC-based sensors provide the best linear result in comparison with the RTD or Thermistors.

At a glance, Thermistor provides the least amount of linearity in comparison with the other types of Sensors. The following chart shows the advantages and disadvantages along with a graphical representation of non-linearity between all four types of sensors in Figure. II [IX, IV, XI]

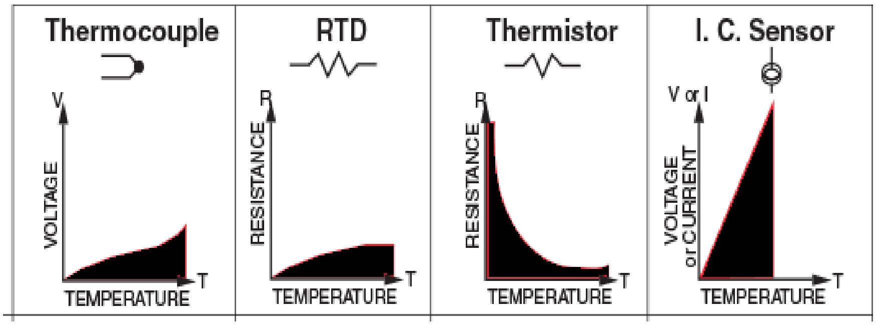

Fig 2. Comparative Analysis Between output response of Different Sensors (Not in scale)

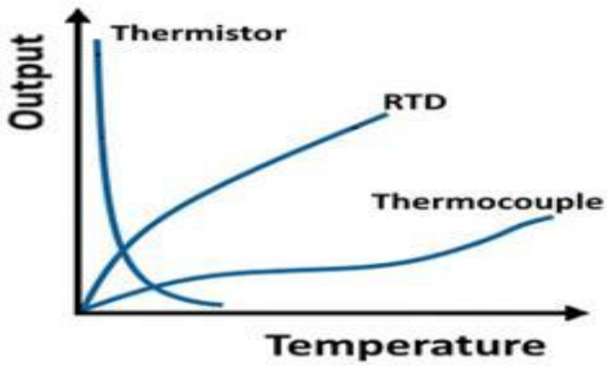

Fig 3. General Comparison between nonlinearity of Different Temperature Sensors (Not in Scale)

The main goal of our work is to design a Universal system comprising both analogue and digital systems. [V, XV] The system will be able to use several analogue and digital sensors, get nonlinear data from them, and convert each nonlinear data into its linear form. The system will bring each converted data under one specific measurement system so that complexity becomes less. Users need not choose a separate system to convert linearized data for different sensors, but the universal linearizer will automatically convert nonlinear values to linear values for a specific number of sensors. In the proposed system several sensors can be connected as an input device but the processed output will be linear and mapped into a specific set of values predefined by the system itself.

Sensor Linearizer for Basic temperature is already Present for implementation [IX]. However, as different linearizer provides different nonlinear outputs it's almost impossible for a single circuit to linearize multiple types of sensors. The basic Linearization flow process is described in Fig 4.

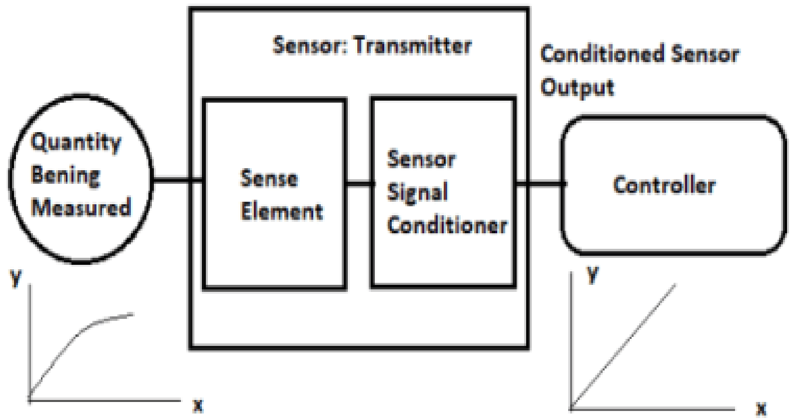

Fig 4. Basic Sensor Linearization workflow

V. Implementing Universal Linearizer

The alternate way through which we can create a universal linearizer is by emulating the behavior of different sensors to a particular sensor. The block diagram below shows the basic concept of the project through which we can create a universal Linearizer. For the project as a base model, we create a basic Neural Network Model for Thermocouple linearization as shown below.

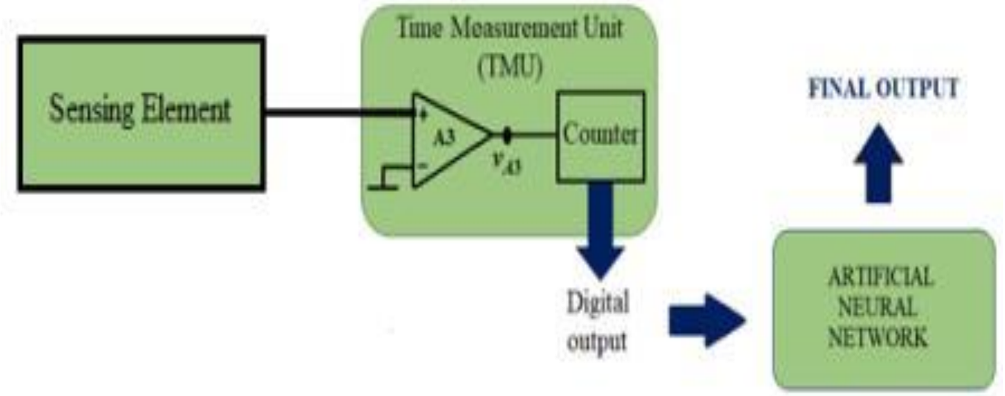

Fig 5. Basic Neural Network-Based Thermocouple Linearizer

The idea is to create a linearizer/converter circuit at the initial stage of the circuit. This circuit will emulate the output of any nonlinear linearizer to the output of a nonlinear thermocouple. As the thermocouple linearizer is already present then it will become easy for the existing circuit to linearize that output to a standard value.

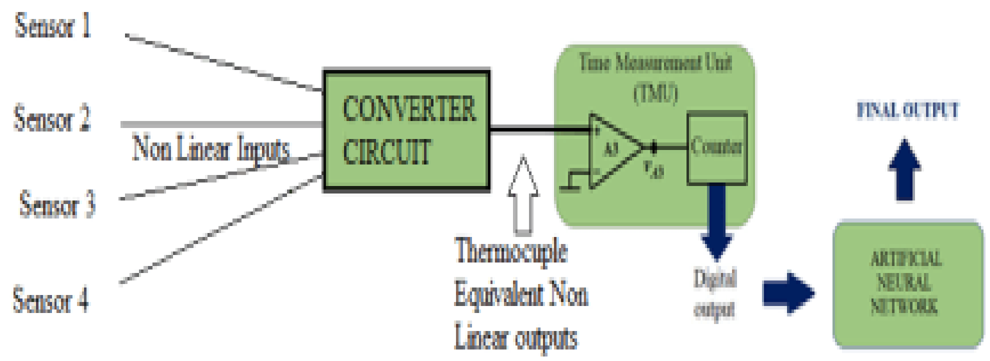

Fig 6. Proposed Universal Linearizer Circuit

As the above Picture Shows the Proposed work. As the non-Linearity between different Sensors is very much different. The project work becomes very Complex and Mathematically Challenging. However, a Universal Linearizer can be used as a great device in Thermometry for easy measurement of temperature in a socio-economic scenario where the choice of sensor is a luxury.

VI. Conclusion

The scarcity of Universal Linearizer has made the industry rely on specific sensors and specific system designs. Which in turn has increased the cost of manufacturing and the use of costly systems. As each sensor shows a separate type of non-linearity it is evident that this situation will prevail until something is done specifically. The goal of this research proposal has been to focus on scientific and economic conditions to ease the difficulty faced by the industry. The invention of the Universal Linearizer will create both scientific breakthroughs as well as will choose a specific sensor for measuring thermometric activities is optional.

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Conflict of Interest:

The authors declare that no conflict of interest to report the present paper

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