Investigation Of A Transfer Function Between Standard 12-Lead ECG And EASI ECG

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An attempt of finding transfer function between standard 12 lead ECG system and EASI ECG system. Various regression techniques, like Least Angle Regression ("LARS"), LASSO, Forward Stagewise, linear regression, were used to find a set of transfer coefficients. Different tools were used (Matlab, R-Project, WEKA) for better problem investigation. Few transfer functions that successfully approximate EASI ECG system were obtained.

1 Introduction

In 1988 Dover and his team [2] introduced EASI ECG system, which derives standard 12 lead ECG using only 5 electrodes. The E electrode is on the sternum while, the A and I electrodes are at the left and right mid-auxiliary lines, respectively. Their location is identical to the one proposed by Frank. The S electrode is at the sternal manubrium. The fifth electrode is a ground and is typically placed on one or the other clavicle [2], see Fig 1 . EASI was proven to have high correlation with standard 12 lead ECG [3-4], as well as with Mason-Likar 12-Lead ECG [5]. Apart from that it is less susceptible to artefacts, increase mobility of patients and is easier to use because of smaller number of electrodes.

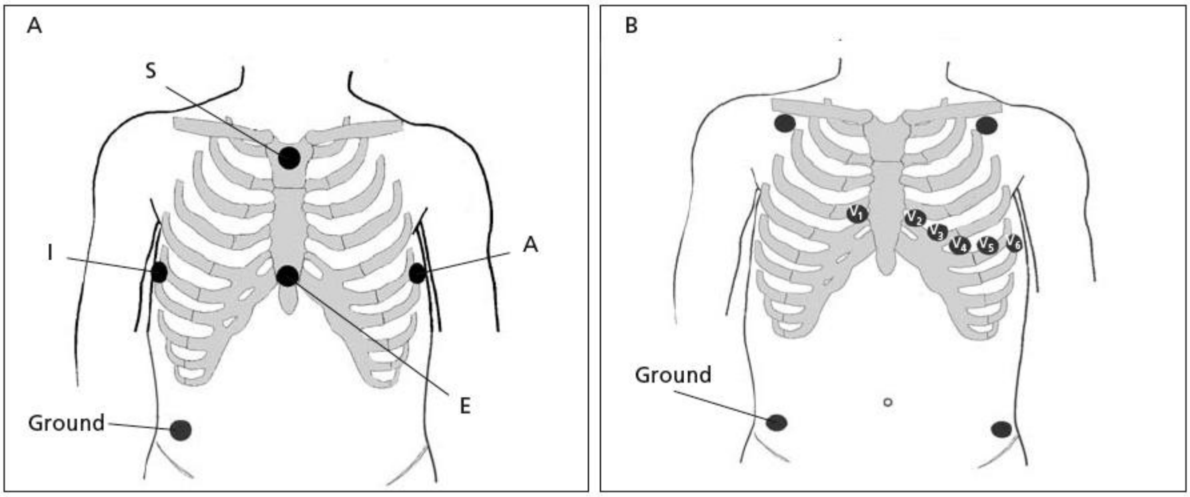

Fig 1.Lead placement for the EASI system (A) and the Mason-Likar (B) 12-lead electrocardiogram.

In the literature there are several papers that describe the way of obtaining standard 12 lead ECG signal from EASI signal, using set of linear equations, however nobody yet tried to find a transfer function that would be used to obtain EASI ECG results from standard 12 lead ECG.

2 Methods

Finding a transfer function between the two ECG systems could be represented as a regression problem with twelve input variables from the standard ECG system (I, II, III, aVR, aVL, aVF, V1, V2, V3, V4, V5, V6) and four output variables from EASI system (*E, A, S, I*). Furthermore, this complex problem could be split into four 12 to 1 regression problems, see Fig 2.

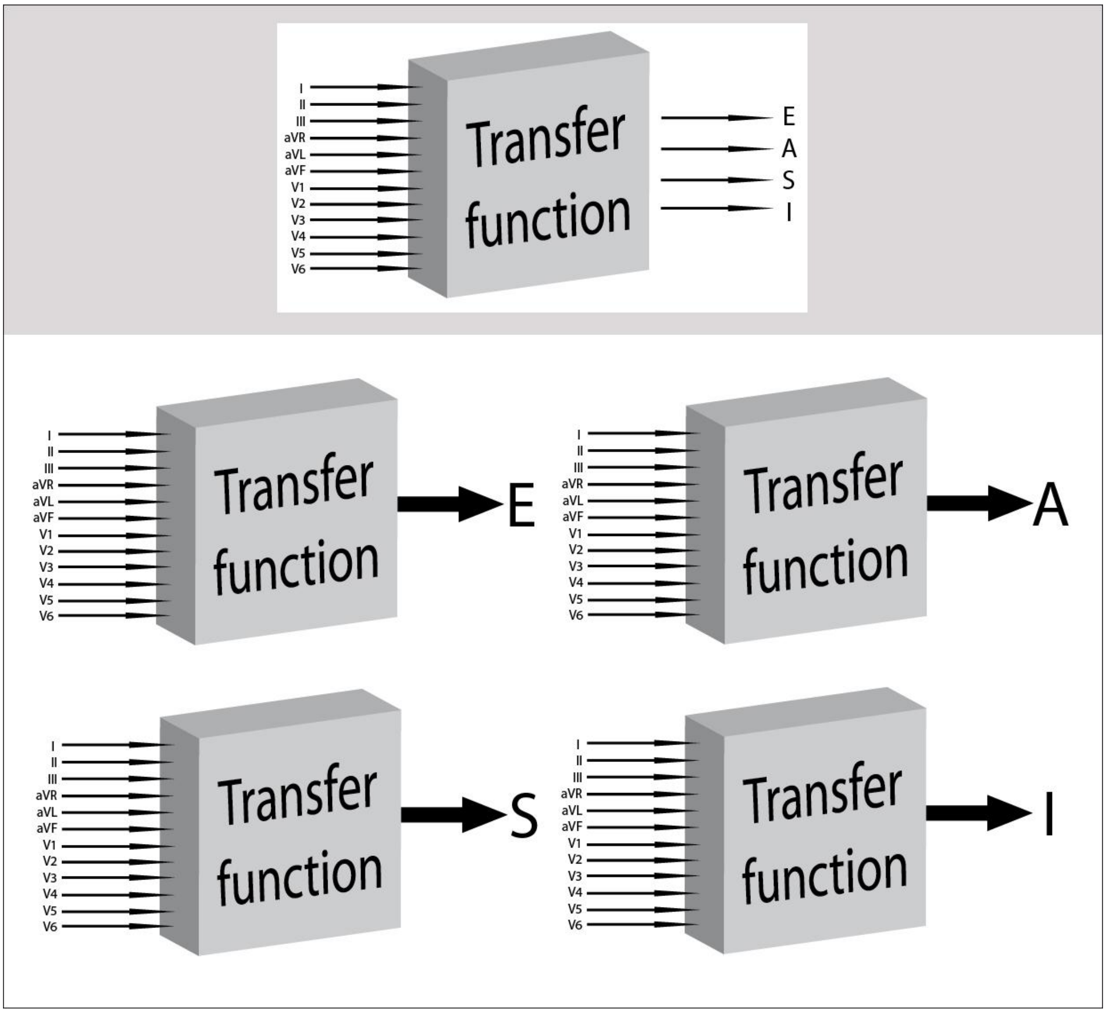

Fig 2. Transformation of 12 to 4 regression problem into four 12 to 1 problems.

In this paper, four different regression techniques, namely: linear regression, Least Angle Regression ("LARS") [1], Lasso [1] and Forward Stagewise [1] were used to obtain the best fitting transfer function. Simple linear regression was computed using WEKA data mining software [6], LARS, Lasso and Forward Stagewise using R-Project software [7] with LARS package [8].

The LARS is related to the classic model-selection method known as Forward Selection, Lasso is a constrained version of ordinary least squares (OLS), and Forward Stagewise is a much more cautious version of Forward Selection, which may take thousands of tiny steps as it moves toward a final model. It turns out that both Lasso and Stagewise are variants of a basic procedure called "Least Angle Regression". For the detailed explanation please read position Least Angle Regression [1].

All results were then imported into Matlab software [9] and there compared.

3 Results

In this section transfer functions for four dependent variables (E,A,S,I) obtained from all four algorithms will be presented. Data used for problem investigation come from PhysioNet database [10].

3.1 Linear regression

Set of equations obtained thanks to linear regression method with application of WEKA tool:

$\boldsymbol{E} = 0.2281*\mathrm{II} - 0.1573*\mathrm{aVR} + 1.4023*\mathrm{V1} - 0.2317*\mathrm{V2} + 0.638*\mathrm{V3} - 0.3104*\mathrm{V4}$
$- 0.5253*\mathrm{V5} + 0.7453*\mathrm{V6} - 6.9118;$
$\boldsymbol{A} = 0.1164*\mathrm{I} + 0.1465*\mathrm{aVL} - 0.0788*\mathrm{V1} + 0.0393*\mathrm{V3} + 0.1462*\mathrm{V5} + 0.5328*\mathrm{V6}$
$- 0.1527;$
$\boldsymbol{S} = -0.4071*\mathrm{II} + 0.2901*\mathrm{aVR} - 0.2391*\mathrm{aVF} - 0.0966*\mathrm{V1} + 0.3609*\mathrm{V2}$
$-0.3269*\mathrm{V3} + 0.2524*\mathrm{V4} + 0.0465*\mathrm{V5} - 0.1319*\mathrm{V6} + 3.2637;$
$\boldsymbol{I} = -0.1073*\mathrm{I} + 0.1136*\mathrm{III} + 0.1023*\mathrm{aVR} - 0.1215*\mathrm{aVL} - 0.1541*\mathrm{V2} + 0.2648*\mathrm{V3}$
$- 0.1715*\mathrm{V4} + 0.0369*\mathrm{V5} - 0.1087*\mathrm{V6} + 0.4418;$

3.2 LARS

Set of equations obtained thanks to LARS regression method with application of R-Project tool with LARS package:

$\boldsymbol{E} = -6.4073889*\mathrm{II} - 4.58091464*\mathrm{aVR} + 4.4236590*\mathrm{aVF} + 1.4023342*\mathrm{V1}$
$- 0.2316670*\mathrm{V2} + 0.63803224*\mathrm{V3} - 0.3104148*\mathrm{V4} - 0.5253245*\mathrm{V5} + 0.7453142*\mathrm{V6};$
$\boldsymbol{A} = 0.1205489*\mathrm{I} + 0.1440902*\mathrm{aVL} - 0.07460267*\mathrm{V1} - 0.005248586*\mathrm{V2}$
$+ 0.04413031*\mathrm{V3} - 0.001846735*\mathrm{V4} + 0.14529887*\mathrm{V5} + 0.5326776*\mathrm{V6};$
$\boldsymbol{S} = -0.9615144*\mathrm{II} + 0.07950829*\mathrm{aVL} + 0.21000511*\mathrm{aVF} - 0.096557012*\mathrm{V1}$
$+ 0.3608502*\mathrm{V2} - 0.32692627*\mathrm{V3} + 0.252434208*\mathrm{V4} + 0.04650518*\mathrm{V5} -0.1318653*\mathrm{V6};$
$\boldsymbol{I} = -0.1494002*\mathrm{I} - 0.24593780*\mathrm{aVL} - 0.003465868*\mathrm{V1} - 0.1516211491*\mathrm{V2}$
$+ 0.2637671*\mathrm{V3} - 0.17090946*\mathrm{V4} + 0.03756737*\mathrm{V5} - 0.10936146*\mathrm{V6};$

3.3 Lasso

Set of equations obtained thanks to Lasso regression method with application of R-Project tool with LARS package:

$\boldsymbol{E} = -0.4167259*\mathrm{III} - 0.03150482*\mathrm{aVR} + 0.707700900*\mathrm{aVF} + 1.4023342*\mathrm{V1}$
$- 0.23166698*\mathrm{V2} + 0.63803224*\mathrm{V3} - 0.31041477*\mathrm{V4} - 0.5253245*\mathrm{V5} + 0.7453142*\mathrm{V6};$
$\boldsymbol{A} = 0.1205489*\mathrm{I} + 0.1440902*\mathrm{aVL} - 0.07460267*\mathrm{V1} - 0.005248586*\mathrm{V2} +$
$0.04413031*\mathrm{V3} - 0.001846735*\mathrm{V4} + 0.14529887*\mathrm{V5} + 0.5326776*\mathrm{V6};$
$\boldsymbol{S} = -11.2986989*\mathrm{II} - 6.97096461*\mathrm{aVR} + 7.02195313*\mathrm{aVF} - 0.09655701*\mathrm{V1} +$
$0.3608502*\mathrm{V2} - 0.32692627*\mathrm{V3} + 0.252434208*\mathrm{V4} + 0.04650518*\mathrm{V5} - 0.13186532*\mathrm{V6};$
$\boldsymbol{I} = -0.1494002*\mathrm{I} - 0.24593780*\mathrm{aVL} - 0.0034658678*\mathrm{V1} - 0.1516211491*\mathrm{V2} +$
$0.26376712*\mathrm{V3} - 0.17090946*\mathrm{V4} + 0.037567365*\mathrm{V5} - 0.10936146*\mathrm{V6};$

3.4 Forward Stagewise

Set of equations obtained thanks to Forward Stagewise regression method with application of R-Project tool with LARS package:

$\boldsymbol{E} = 0.099578798*\mathrm{I} + 0.08434988*\mathrm{II} + 0.008679116*\mathrm{III} - 0.13315694*\mathrm{aVR}$
$- 0.007053778*\mathrm{aVL} + 1.435931e\text{-}01*\mathrm{aVF} + 1.4023342*\mathrm{V1} - 0.2316670*\mathrm{V2}$
$+ 0.6380322415*\mathrm{V3} - 3.104148e\text{-}01*\mathrm{V4} - 0.525324541*\mathrm{V5} + 7.453142e\text{-}01*\mathrm{V6};$
$\boldsymbol{A} = 0.2826810*\mathrm{I} - 0.010144385*\mathrm{II} - 0.298382829*\mathrm{III} + 0.27564421*\mathrm{aVR}$
$+ 0.011399265*\mathrm{aVL} + 3.800039e\text{-}01*\mathrm{aVF} - 0.07460267*\mathrm{V1} - 5.248586e\text{-}03*\mathrm{V2}$
$+ 0.04413031*\mathrm{V3} - 1.846735e\text{-}03*\mathrm{V4} + 0.1452989*\mathrm{V5} + 0.5326776*\mathrm{V6};$

S = *-0.021319372**I - *0.7014857**II + *6.339136e-03**III + *0.0611922792**aVR - *0.06552077**aVF - *0.096557012**V1 + *0.3608502**V2 – *0.326926273**V3 + *2.524342e-01**V4 + *0.046505183**V5 - *1.318653e-01**V6;

I = *-0.3556918**I - *2.19893239**II + *0.004653325**III – *1.54710987**aVR - *0.04893501**aVL + *1.519226**aVF - *0.0034658678**V1 – *0.15162115**V2 + *0.2637671157**V3 - *0.17090946**V4 + *0.0375673652**V5 - *1.093615e-01**V6;

3.5 Error measurements

To measure the efficiency of regression method used both RMSE, see Fig. 4 and maximal error in percentage were computed, please see table below:

WEKA_E	LARS_E	Lasso_E	Forward_E
9.4353	9.8028	9.8028	9.8028
WEKA_A	**LARS_A**	**Lasso_A**	**Forward_A**
9.4353	1.9134	1.9134	1.9134
WEKA_S	**LARS_S**	**Lasso_S**	**Forward_S**
9.4353	11.6006	11.6006	11.6006
WEKA_I	**LARS_I**	**Lasso_I**	**Forward_I**
9.4353	7.3358	7.3358	7.3359

Tab 1. Table with maximal obtained error in percentage.

From this comparison one can notice that regression method based on LARS algorithm produce a better results.

4 Tables

In this section a table showing process of transfer function calculation and input variable reduction will be presented.

	[I]	[II]	[III]	[aVR]	[aVL]	[aVF]	[V1]	[V2]	[V3]	[V4]	[V5]	[V6]
[1,]	0	0.0000000	0	0.00000000	0	0.0000000	0.0000000	0.0000000	0.00000000	0.0000000	0.0000000	0.0000000
[2,]	0	0.0000000	0	0.00000000	0	0.0000000	0.4076648	0.0000000	0.00000000	0.0000000	0.0000000	0.0000000
[3,]	0	0.0000000	0	0.00000000	0	0.0000000	0.8211082	0.2639655	0.00000000	0.0000000	0.0000000	0.0000000
[4,]	0	0.0000000	0	0.00000000	0	0.1045743	0.7611191	0.3296847	0.00000000	0.0000000	0.0000000	0.0000000
[5,]	0	0.2139751	0	0.00000000	0	0.0868405	0.8692921	0.3174362	0.00000000	0.0000000	0.0000000	0.0000000
[6,]	0	0.1294397	0	0.00000000	0	0.2077453	0.8800242	0.2803886	0.06242149	0.0000000	0.0000000	0.0000000
[7,]	0	-0.2318489	0	0.00000000	0	0.4219143	0.9459851	0.3912792	-0.11323240	0.0000000	0.0000000	0.2833833
[8,]	0	-0.1207744	0	0.00000000	0	0.3367719	1.0217387	0.2549361	0.07253338	-0.1256417	0.0000000	0.3001544
[9,]	0	0.4639831	0	0.00000000	0	-0.1572556	1.4023342	-0.2316670	0.63803224	-0.3104148	-0.5253245	0.7453142
[10,]	0	0.4097591	0	-0.03614935	0	-0.1211063	1.4023342	-0.2316670	0.63803224	-0.3104148	-0.5253245	0.7453142
[11,]	0	-0.1886359	0	-0.43507936	0	0.2778237	1.4023342	-0.2316670	0.63803224	-0.3104148	-0.5253245	0.7453142
[12,]	0	-0.7285119	0	-0.79499665	0	0.6377410	1.4023342	-0.2316670	0.63803224	-0.3104148	-0.5253245	0.7453142
[13,]	0	-6.4073889	0	-4.58091464	0	4.4236590	1.4023342	-0.2316670	0.63803224	-0.3104148	-0.5253245	0.7453142

Tab 2. Table obtained for dependent variable E for LARS algorithm.

5 Figures

In this section plots of transfer functions and boxplot with errors will be presented.

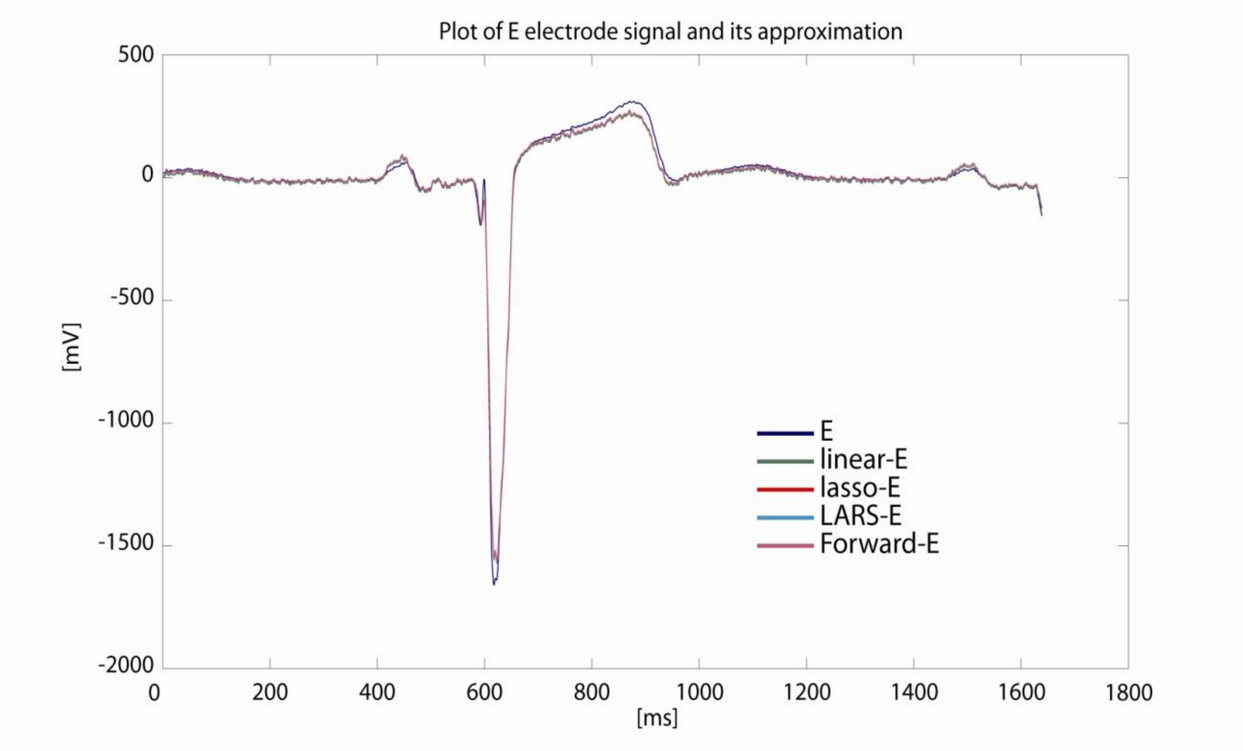

Fig 3. Plot of signal from E electrode and signals derived with application of four Transfer Functions

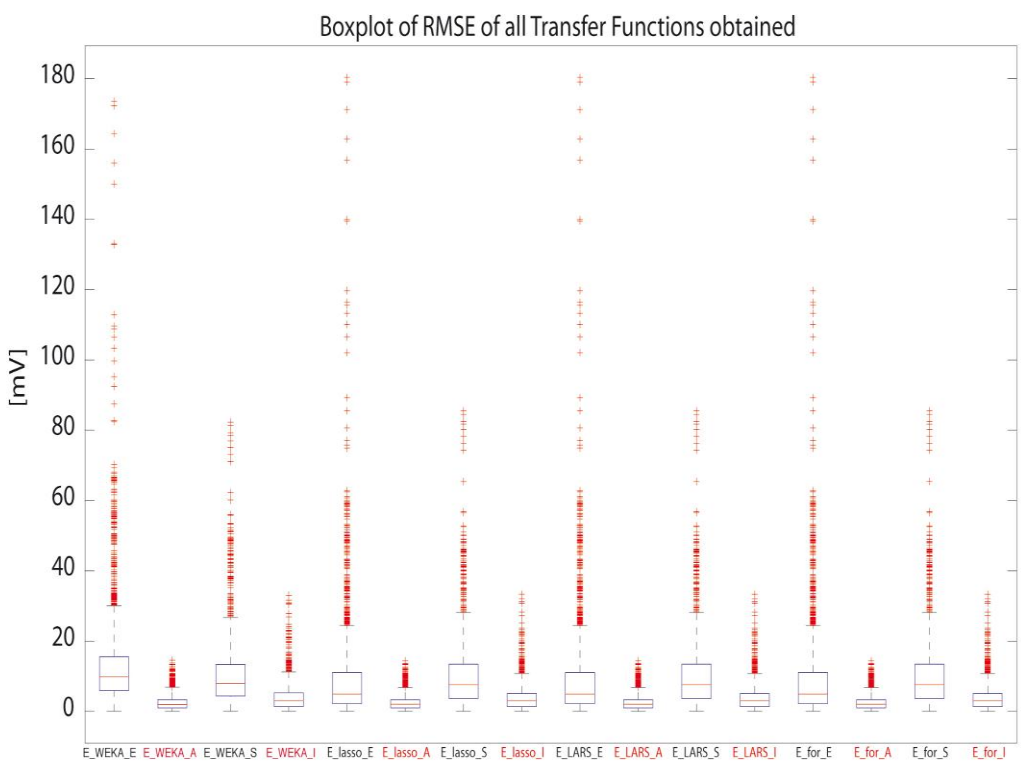

Fig 4.Boxplot representig RMSE of all Transfer Functions obtained.

6 Conclusions

One can notice that transfer functions obtained form various regression methods differ a lot in case of their equations, however all of them produce a very comparable results. Basing on RMSE calculations we can make a conclusion, that regression methods based on LARS algorithm give better results. Thanks to transfer functions obtained, one can now simulate the behaviour of EASI ECG system having results from standard 12 leads ECG system. This is especially desired, because the number of free data sets with both systems used is not significant. What is more, the transfer functions obtained can be useful for further work on finding best fitting functions and set of equations describing relation between EASI ECG system and standard ECG system, which is crucial for further development and popularization of EASI method.

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