

## INDEPENDENCE TEST OF GAMELAN INSTRUMENTS SIGNAL IN TIME DOMAIN AND FREQUENCY DOMAIN

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### Abstrak

Gamelan merupakan salah satu warisan budaya Indonesia yang sudah diakui dunia sehingga perlu dilestarikan di antaranya dengan melakukan penelitian terhadapnya. Untuk menganalisa gamelan yang merupakan suatu orkestra dari beberapa instrumen diperlukan pemisahan di antara sinyal-sinyal instrumen gamelan tersebut. Salah satu metode pemisahan yang cukup handal adalah Independent Component Analysis (ICA) yang mensyaratkan komponen-komponennya independen secara statistik. Pada penelitian ini uji independensi pada sinyal gamelan dilakukan dengan menggunakan metode statistik non-parametrik yaitu Least-Square Independence Test (LSIT). Pada pengolahan sinyal digital terdapat dua domain yaitu domain waktu dan domain frekuensi. Uji independensi dilakukan pada setiap pasang sinyal instrumen gamelan dari keluarga balungan yaitu Demung, Saron, dan Peking tidak hanya dalam domain waktu namun juga domain frekuensi. Hasil penelitian menunjukkan nilai Squared-Loss Mutual Information (SMI) hasil LSIT pada domain waktu lebih rendah daripada nilai SMI hasil LSIT pada domain frekuensi. Hal ini mungkin disebabkan oleh pengaruh dari Fast Fourier Transform (FFT) dimana tidak semua hasil transformasi pada domain frekuensi digunakan namun hanya meliputi frekuensi dasarnya saja.

Kata kunci: uji independensi, gamelan, LSIT, domain waktu, domain frekuensi .

### Abstract

*Gamelan is one of Indonesian cultural heritage that has been recognized worldwide that need to be preserved such as doing some researches. Analyzing gamelan that plays like an orchestra of several instruments is needed separation between them. One of powerful separation method is Independent Component Analysis (ICA) that has prerequisite independent statistically for its components. In this research we use non-parametric statistical independence test, i. e. Least-Square Independence Test (LSIT). In digital signal processing there are two domain, e.g. time domain and frequency domain. The independence test is held for balungan group that consists of Demung, Saron, and Peking signals not only in time-domain but also frequency-domain. The results show that the Squared-Loss Mutual Information (SMI) value of LSIT in time-domain is lower than that in frequency domain. This may be due to the influence of Fast Fourier Transform (FFT) where not all of the results in the frequency domain transformations used but only just covering the fundamental frequency.*

*Key words: independence test, gamelan, LSIT, time domain, frequency domain.*

## INTRODUCTION

Identifying the statistical independence of random variables depends on their distribution [1]. A classic independence test is the Pearson correlation coefficient that is useful for Gaussian data. In practice, data in Gaussian distribution is rarely found. Therefore, the independence of such non-Gaussian data is well-evaluated by using a non-parametric statistical independence test. There are many researches of distribution-free independence test, for example: Chiu, et. al. [2] use multivariate uniformity for speech signals, Ihler, et. al. [3] use machine learning approach for image signals, Ku and Fine [4] use Bayesian procedure for sample data, Geenens, et. al.[5] use two-way contingency tables for insurance data, and, Sugiyama and Suzuki [6] use Least-Square Independence Test (*LSIT*) for toy datasets.

We focus our research on the signals produced by instruments of gamelan, i.e. Balungan group, which are Saron Demung (Demung), Saron Bonang (Saron), and Saron Penerus (Peking) (see Figure 1.). Demung is one octave below Saron, while Peking is an octave above Saron. We have detected that the signals of these instruments have non-Gaussian distribution [7]. Also, we have done independent test by using *LSIT* on that signals but only in time-domain from one gamelan set [8]. Musical signal as sinusoidal complex is suitable to be analyzed on frequency-domain [9]. It motivates us to test independence of gamelan instruments signals not only in time-domain but also in frequency-domain.

Meanwhile, gamelan is hand-made and constructed manually based on the gamelan masters's feeling and experience. On the other hand, the player style e.g. the strength of the hit and the location of attack area, also contributes some variations in produced gamelan signals. These conditions cause the frequency of signals, signal envelope and harmonic contents of instrument's sound in one gamelan can be different from that in other gamelan (see Table 1.)

Although gamelan is played like an orchestra but each instrument produces monophonic audio signals which every tone has a fundamental frequency [10]. Due to these facts, it has been an important issue



Figure 1. The Balungan Group

Table 1. Fundamental Frequency of Saron from Several Gamelan Sets [10]

Notation	Fundamental Frequency (Hz)			
	Set 1	Set 2	Set 3	Set 4
Saron1	528	528	504	539
Saron2	610	610	574	610
Saron3	703	703	688	703
Saron5	797	762	792	799
Saron6	915	922	879	926

to detect the statistical independence between signals of gamelan instruments not only in time domain but also in frequency domain from Demung, Saron, and Peking signals using *LSIT*.

## RESEARCH METHODS

In this section we describe theories for independent test of gamelan instruments signal based on *LSIT* in time domain and frequency domain. The stages of the research are depicted in Figure 2.

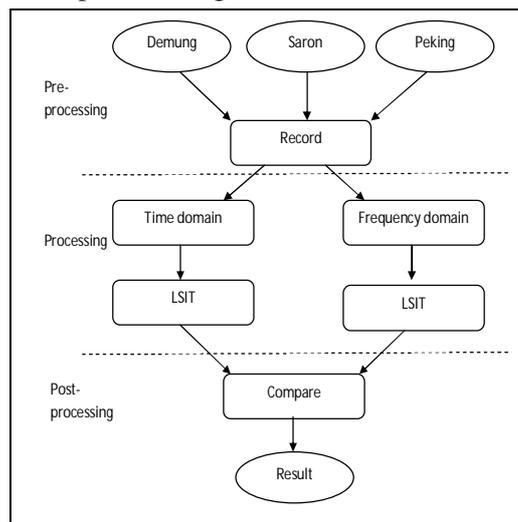


Figure 2. The Stages of The Research

For pre-processing we recorded gamelan instruments from a gamelan sets that consist of Demung, Saron, and Peking. In processing, there are two parts, which are

independence test using LSIT in time domain and frequency domain. The last is comparing the value of SMI to get the performance of the method.

**Time Domain**

Signal can be represented through the spectral representation. The most common way is in the form of gray scale image which represents the magnitude value at any given time. The higher value of magnitude is the higher deviation of wave at that time. Figure 3 represents signals of gamelan instruments in time domain. The appearance of each signal in time domain is looks similar to each other.

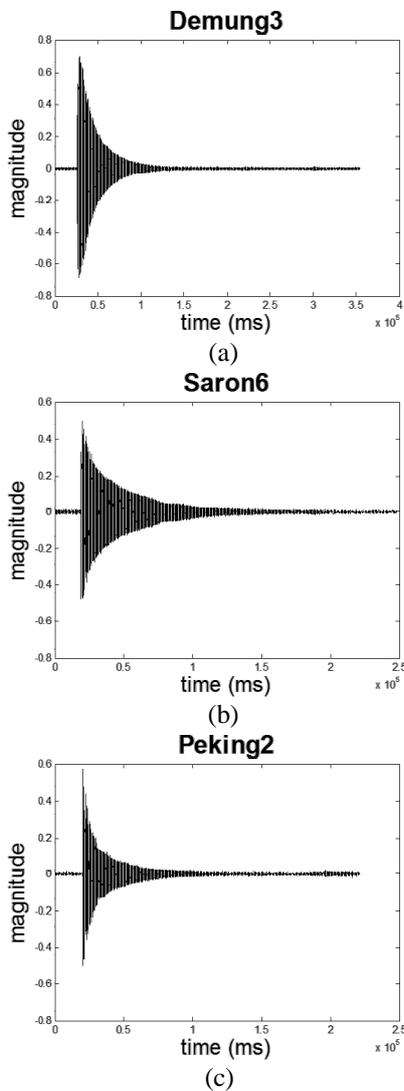


Figure 3. Gamelan Signals in Time Domain

**Frequency Domain**

One way to transform the signal from time domain to frequency domain is using the Discrete Fourier Transform (DFT) [9]. DFT can be expressed in Equation (1).

$$X_k = \sum_{n=0}^{N-1} x_n W_N^{kn} \quad , k = 0, 1, 2, \dots, N-1 \quad (1)$$

where  $W_N = e^{-j\frac{2\pi}{N}}$  with  $j = \sqrt{-1}$  and  $N$  is number of data.

Figure 4 represents signals from Figure 3. In frequency domain using Equation (1).

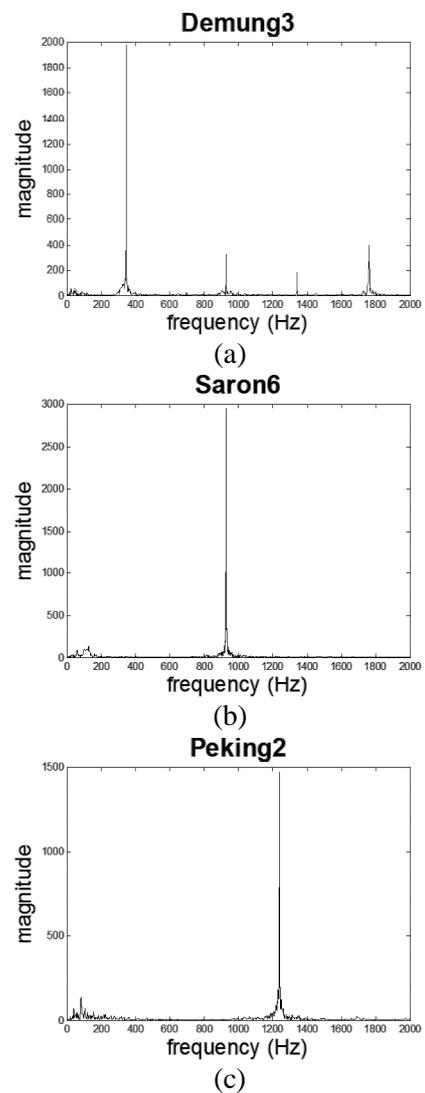


Figure 4. Gamelan Signals in Frequency Domain.

The advantage of using frequency domain is the number of sample lower than time domain, but the data is in complex number.

**Definition of Independence**

Data  $\mathbf{x}$  and  $\mathbf{y}$  are said to be independent if information of  $\mathbf{x}$  does not give any information on  $\mathbf{y}$ , and vice versa [6]. Let  $p_{XY}(\mathbf{x}, \mathbf{y})$  is *joint-probability density function (pdf)* of  $\mathbf{x}$  and  $\mathbf{y}$ . Then  $p_X(\mathbf{x})$  and  $p_Y(\mathbf{y})$  is the *marginal-pdf* of  $\mathbf{x}$  and  $\mathbf{y}$  respectively. Thus,  $\mathbf{x}$  and  $\mathbf{y}$  are said to be independent if and only if the *joint pdf* of  $\mathbf{x}$  and  $\mathbf{y}$  can be factored in Eq. (2).

$$p_{XY}(\mathbf{x}, \mathbf{y}) = p_X(\mathbf{x}) \cdot p_Y(\mathbf{y}) \tag{2}$$

Computing Equation (2) directly from data is a hard task, so we need a method to estimate the independence of signals. In this paper we use least-square.

**Least-Squares Independence Test**

Least-Square is a statistical method that can be used to determine the relationship or correlation between the two variables using the regression equation. *Least-Squares Independence Test (LSIT)* is an independence test based on the *Squared-Loss Mutual Information (SMI)* and the estimation of *Least-Squares Mutual Information (LSMI)* [6]. *SMI* is defined in Equation (3). For simplicity,  $p_{XY}(\mathbf{x}, \mathbf{y})$  represents as  $p(\mathbf{x}, \mathbf{y})$ ,  $p_X(\mathbf{x})$  as  $p(\mathbf{x})$ , and  $p_Y(\mathbf{y})$  as  $p(\mathbf{y})$ .

$$SMI = \frac{1}{2} \iint p(\mathbf{x})p(\mathbf{y}) \left( \frac{p(\mathbf{x}, \mathbf{y})}{p(\mathbf{x})p(\mathbf{y})} - 1 \right)^2 d\mathbf{x}d\mathbf{y} \tag{3}$$

$\mathbf{x}$  and  $\mathbf{y}$  are said to be statistically independent if and only if *SMI* is zero. To calculate *SMI* we decide density ratio as Equation (4).

$$r(\mathbf{x}, \mathbf{y}) = \frac{p(\mathbf{x}, \mathbf{y})}{p(\mathbf{x})p(\mathbf{y})} \tag{4}$$

Since *pdf* of  $p(\mathbf{x}, \mathbf{y})$ ,  $p(\mathbf{x})$  and  $p(\mathbf{y})$  are unknown, approximate the density ratio using Equation (5).

$$\hat{r}(\mathbf{x}, \mathbf{y}) = \sum_{l=1}^b a_l \psi_l(\mathbf{x}, \mathbf{y}) = \mathbf{a}^T \boldsymbol{\psi}(\mathbf{x}, \mathbf{y}) \tag{5}$$

where  $\boldsymbol{\psi}(\mathbf{x}, \mathbf{y})$  is a non-negative basis function vector,  $\mathbf{a}$  is a parameter vector, and  $^T$  denotes the transpose.

When  $\hat{r}$  is gained, we can approximate *SMI* using Equation (6).

$$SMI \approx \frac{1}{n} \sum_{i=1}^n \hat{r}(\mathbf{x}_i, \mathbf{y}_i) - \frac{1}{2n^2} \sum_{i,j=1}^n \hat{r}(\mathbf{x}_i, \mathbf{y}_j)^2 - \frac{1}{2} \tag{6}$$

**RESULT AND DISCUSSION**

Our data in this research are instrument signals of Demung, Saron, and Peking that are recorded from Gamelan Elektro Budoyo from Department of Electrical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya (ITS). The gamelan was held on an open stage, so we assume that the recorded signals have no echoes and free from noise.

There are two tuning system in gamelan: *Pelog* and *Slendro*. In *Slendro* tuning system every instrument of Balungan has five tones: 1 ('*Ji*'), 2 ('*Ro*'), 3 ('*Lu*'), 5 ('*Mo*'), and 6 ('*Nem*'). In our experiments we use pattern [abbreviation instrument][tone number], e.g., 'd3' means signal of Demung tone 3 ('*Lu*'), 's6' means signal of Saron tone 6 ('*Nem*'), and 'p2' means signal of Peking tone 2 ('*Ro*').

The fundamental frequency range of Demung, Saron, and Peking is about 250 Hz – 1900 Hz. This facts allow us to take sample  $n = 4000$  in time-domain to avoid aliasing and  $n = 2000$  in frequency-domain due to the range of the fundamental frequency.

**Experiment Performance**

The experimental data obtained from recording of gamelan instruments from Gamelan Elektro Budoyo ITS. Signals are recorded in 16-bit, mono-channel, and frequency sampling 48000 Hz. The gamelan instruments are Demung, Saron, and Peking in *Slendro* tuning. Every instrument has 5 blades that recorded 10 times. Then we pick randomly pairs of signals from different blade. Because of each blade has 10 signals then we can test every pair 100 times to get the value of *SMI*.

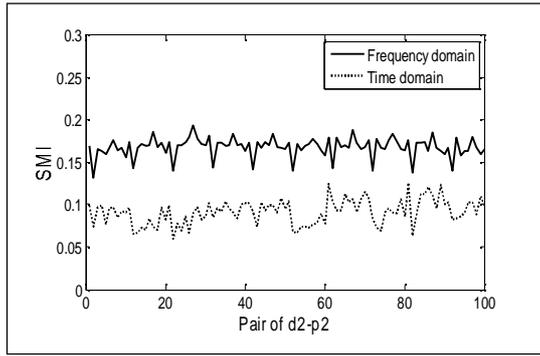


Figure 5. The Stability of SMI from Demung tone 2 and Peking tone 2

Table 2. The value of SMI from Demung, Saron, and Peking Signals

Signals	Time domian		Frequency domain	
	Different	Same	Different	Same
Mean	0.06316	2.06291	0.28954	10.16853
Min	0.00001	1.36881	0.03826	4.68128
Max	0.23663	3.59578	0.77557	20.46387

For example, Figure 5. indicates the stability of SMI value from Demung2 and Peking2 in time-domain and frequency-domain.

The value of SMI in time domain is lower than in frequency domain. But the varian of time domain is higher than frequency domain.

However, the all value of SMI indicated that the signal pair of Demung tone 2 (d2) and Peking tone 2 (p2) is mutually independent.

Further more we test independence between two signals of Demung, Saron and Peking in time domain and frequency domain as shown in Figure 6 and Figure 7.

Figure 6 shows the value of SMI in time domain based on Table 3 while Figure 7 shows the value of SMI in frequency domain based on Table 4.

The value of SMI in time domain and frequency domain from different signals proves that they are independent statistically. While signal with itself that dependent definitely (grey-shading in the table) has value of SMI more than 1.

The Table 2. shows the value of SMI in time domain is lower than in frequency domain. This may be due to the influence of FFT where not all of the results in the frequency domain transformations used but only just covering the fundamental frequency.

### CONCLUSION

We could test the independence between two signals of Balungan group in time domain and frequency domain using LSIT. The value of SMI in time domain usually lower than that in frequency domain.

In future works, it should be detected the independence of gamelan instruments signals that have same fundamental frequency like Saron and Bonang. The experiment not only be conducted on various kind of instruments but also in other gamelan sets.

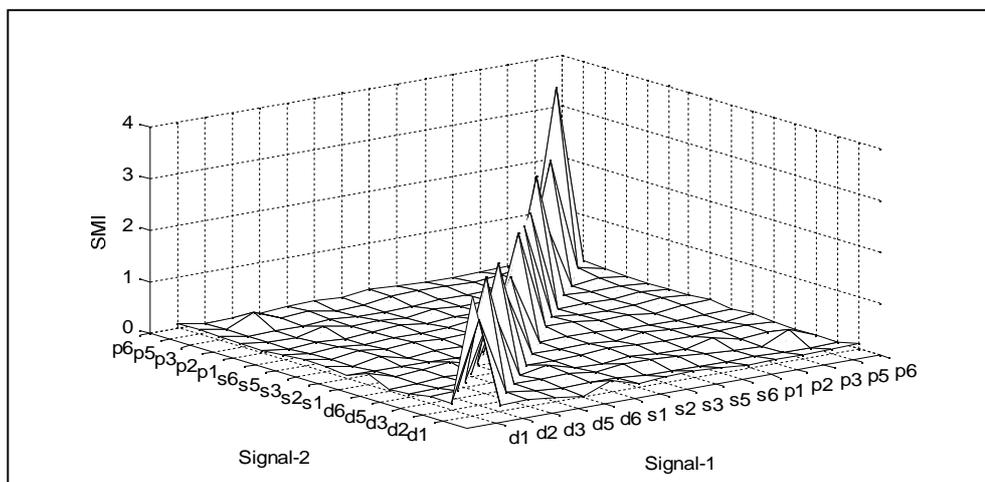


Figure 6. The Value of SMI in Time Domain

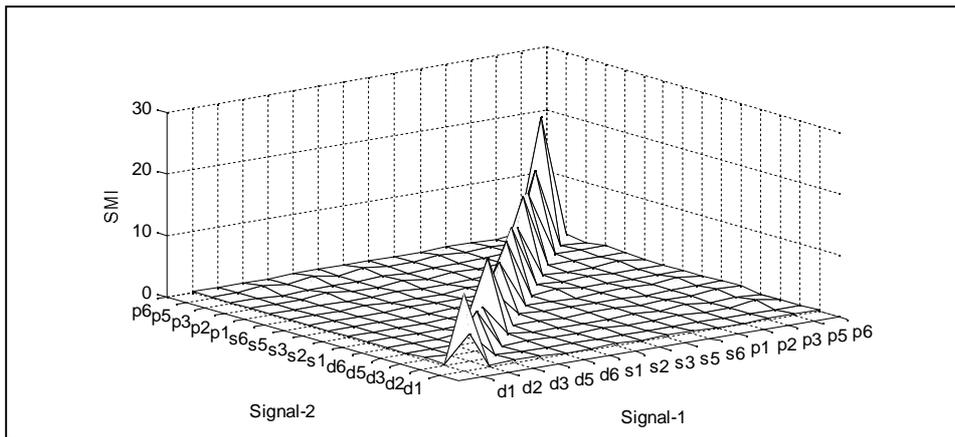


Figure 7. The Value of SMI in Frequency Domain.

### ACKNOWLEDGEMENTS

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Table 3. The value of SMI in time domain

time	d1	d2	d3	d5	d6	s1	s2	s3	s5	s6	p1	p2	p3	p5	p6
<b>d1</b>	2.33437	0.13300	0.14254	0.07392	0.01970	0.20823	0.07205	0.11584	0.13211	0.08780	0.06101	0.07969	0.07240	0.09253	0.09812
<b>d2</b>	0.13300	1.65919	0.14579	0.07768	0.05932	0.05788	0.04945	0.01250	0.02299	0.01170	0.00003	0.00206	0.00005	0.00005	0.00005
<b>d3</b>	0.14254	0.14579	2.28991	0.11184	0.09075	0.10189	0.05910	0.13138	0.10865	0.07644	0.04544	0.00172	0.00188	0.23663	0.02229
<b>d5</b>	0.07392	0.07768	0.11184	1.42155	0.05781	0.15207	0.02363	0.00533	0.04538	0.00374	0.00422	0.11857	0.00001	0.04706	0.00008
<b>d6</b>	0.01970	0.05932	0.09075	0.05781	2.10980	0.04941	0.03443	0.05122	0.07955	0.05581	0.03401	0.02591	0.03644	0.07980	0.03992
<b>s1</b>	0.20823	0.05788	0.10189	0.15207	0.04941	1.36881	0.03489	0.02223	0.03964	0.02755	0.08223	0.04948	0.00001	0.00009	0.07664
<b>s2</b>	0.07205	0.04945	0.05910	0.02363	0.03443	0.03489	1.42938	0.04688	0.05539	0.04950	0.00745	0.00526	0.00857	0.01252	0.03301
<b>s3</b>	0.11584	0.01250	0.13138	0.00533	0.05122	0.02223	0.04688	2.03943	0.14490	0.12382	0.03339	0.08069	0.00568	0.08935	0.09699
<b>s5</b>	0.13211	0.02299	0.10865	0.04538	0.07955	0.03964	0.05539	0.14490	1.96027	0.11984	0.05364	0.04947	0.05595	0.09628	0.07988
<b>s6</b>	0.08780	0.01170	0.07644	0.00374	0.05581	0.02755	0.04950	0.12382	0.11984	2.00856	0.04890	0.05208	0.05595	0.09275	0.05067
<b>p1</b>	0.06101	0.00003	0.04544	0.00422	0.03401	0.08223	0.00745	0.05339	0.05364	0.04890	2.51908	0.10475	0.07924	0.09368	0.05480
<b>p2</b>	0.07969	0.00206	0.00172	0.11857	0.02591	0.04948	0.00526	0.08069	0.04947	0.05208	0.10475	1.52850	0.07128	0.11857	0.06349
<b>p3</b>	0.07240	0.00005	0.00188	0.00001	0.03644	0.00001	0.00857	0.00568	0.05595	0.05595	0.07924	0.07128	2.38747	0.19788	0.07169
<b>p5</b>	0.09253	0.00005	0.23663	0.04706	0.07980	0.00009	0.01252	0.08935	0.09628	0.09275	0.09368	0.11857	0.19788	3.59578	0.11446
<b>p6</b>	0.09812	0.00005	0.02229	0.00008	0.03992	0.07664	0.03301	0.09699	0.07988	0.05067	0.05480	0.06349	0.07169	0.11446	2.29152

Table 4. The value of SMI in frequency domain

Freq	d1	d2	d3	d5	d6	s1	s2	s3	s5	s6	p1	p2	p3	p5	p6
d1	12.75976	0.24061	0.45317	0.38824	0.20823	0.27599	0.32977	0.16626	0.29092	0.27683	0.19939	0.17815	0.17433	0.24788	0.21467
d2	0.24061	4.68128	0.38778	0.22744	0.31090	0.26230	0.17936	0.13991	0.13599	0.15533	0.17361	0.13074	0.12373	0.11177	0.09402
d3	0.45317	0.38778	6.72194	0.29049	0.35091	0.25736	0.21465	0.28457	0.14406	0.13571	0.24552	0.10883	0.03826	0.64388	0.10769
d5	0.38824	0.22744	0.29049	5.60428	0.61762	0.24260	0.26228	0.11058	0.20359	0.36972	0.13713	0.60439	0.06307	0.18168	0.06686
d6	0.20823	0.31090	0.35091	0.61762	12.01188	0.34889	0.31694	0.23096	0.30927	0.22946	0.17016	0.20407	0.21309	0.77557	0.32740
s1	0.27599	0.26230	0.25736	0.24260	0.34889	5.03578	0.49884	0.34331	0.32902	0.24912	0.36972	0.12739	0.18911	0.19611	0.40781
s2	0.32977	0.17936	0.21465	0.26228	0.31694	0.49884	8.11265	0.42848	0.33999	0.04950	0.19887	0.56677	0.23255	0.65359	0.24552
s3	0.16626	0.13991	0.28457	0.11058	0.23096	0.34331	0.42848	9.76164	0.33023	0.65118	0.18597	0.18512	0.11508	0.28296	0.28926
s5	0.29092	0.13599	0.14406	0.20359	0.30927	0.32902	0.33999	0.33023	10.45661	0.41055	0.18920	0.55626	0.17523	0.24041	0.22344
s6	0.27683	0.15533	0.13571	0.36972	0.22946	0.24912	0.04950	0.65118	0.41055	8.95269	0.44567	0.17445	0.17523	0.59833	0.22343
p1	0.19939	0.17361	0.24552	0.13713	0.17016	0.36972	0.19887	0.18597	0.18920	0.44567	12.26946	0.42011	0.41264	0.49562	0.45213
p2	0.17815	0.13074	0.10883	0.60439	0.20407	0.12739	0.56677	0.18512	0.55626	0.17445	0.42011	10.75753	0.55264	0.60439	0.53253
p3	0.17433	0.12373	0.03826	0.06307	0.21309	0.18911	0.23255	0.11508	0.17523	0.17523	0.41264	0.55264	13.42206	0.43761	0.11996
p5	0.24788	0.11177	0.64388	0.18168	0.77557	0.19611	0.65359	0.28296	0.24041	0.59833	0.49562	0.60439	0.43761	20.46387	0.61225
p6	0.21467	0.09402	0.10769	0.06686	0.32740	0.40781	0.24552	0.28926	0.22344	0.22343	0.45213	0.53253	0.11996	0.61225	11.51649