Biuletyn WAT
Vol. LVIII, Nr 3, 2009

Vaccination in ship immune system

TOMASZ PRACZYK

Polish Naval Academy, Śmidowicza 69 Str., Gdynia, Poland

Abstract. The task of the ship immune system is to differentiate self objects, i.e., objects that are not dangerous for our ship, from other objects that can be a potential threat. To perform the task, the system makes use of a set of detectors. The detectors imitate signatures of non-self objects, however, to generate them the signatures of self objects are used. Real signatures of non-self objects are usually unobtainable and therefore they are not used to produce the system. However, situations sometimes happen when the information about non-self objects is accessible. In such a case, the information mentioned can be used to improve performance of the system. To test the ship immune system build based on signatures of both self and non-self objects, experiments were carried out. In the experiments, the task of the system was to differentiate self ship radio stations from non-self ones. Results of the experiments are presented at the end of the paper.
Keywords: identification, artificial immune system
Universal Decimal Classification: 007

1. Introduction

Ship Immune System (SIS) [8, 9] is Artificial Immune System (AIS) [1, 2, 3, 4, 5, 6, 7] whose the main task is to differentiate self ships from non-self ones. The identification of ships is performed based on their signatures, e.g., radio signals generated by ship radio stations. To identify a ship, its signature is compared to detectors memorized in SIS. If at least one detector is similar to the signature, the ship is considered to be non-self (negative detection scheme). Otherwise, it is treated as a self one.

In SIS, the detectors are generated at random. All detectors which classify self ships as non-self ones are removed. The remaining detectors are used as mature detectors to identify ships. Generally, in SIS, the detectors can be in the form of real valued, integer valued or binary vectors [8]. Real valued detectors were tested in [9]. The experiments showed that SIS equipped with such detectors outperforms such methods as *k*NN (*k* Nearest Neighbours) and PNN (Probabilistic Neural Network) [10]. In the experiments, ships were represented by radio signals.

As mentioned above, in SIS and generally in most varieties of AIS, the detectors are generated at random. To eliminate damaging detectors, signatures of self ships are used. Signatures representing non-self ships are not necessary to prepare the system. It is great advantage of SIS because the signatures of non-self ships are very often unobtainable. Even though the access to data about non-self ships is very difficult it is not impossible. The problem is how to make use of the data mentioned to improve effectiveness of the system. In the natural immune system, non-self elements are intentionally introduced to the system in the form of a vaccine. The main goal of such a procedure is to make the system sensitive to objects similar to these from the vaccine. The natural immune system equipped with the information about the form of a potential danger produces appropriately constructed detectors prepared to fight against this danger. In SIS, a similar procedure can be applied. The system can mainly be formed based on randomly generated detectors (regular detectors). The remaining detectors (anti-vaccine detectors) should be geared towards detecting non-self ships of known signatures.

To test effectiveness of the vaccination in SIS, experiments were carried out. In the experiments, two methods of the vaccination were compared. In addition to vaccinated variants of SIS, in the experiments, a variant of SIS built exclusively based on signatures of self ships, was also tested. The task of all the variants tested was to differentiate self ship radio stations from non-self ones.

The paper is organized as follows: section 2 outlines SIS; section 3 presents the concept of vaccinating in SIS; section 4 reports the experiments, and section 5 summarizes the paper.

2. The concept of SIS

Generally, SIS works like AIS. So, at first the set of signatures representing self ships is created. The signatures from this set are used to create the set of mature detectors imitating non-self ships. Once the set of self signatures is created, the system starts to generate immature detectors. The immature detectors are generated at random. Each immature detector is compared to all self signatures. To survive and to become mature, an immature detector has to be different from all self signatures. Otherwise, it is eliminated and replaced with other a randomly generated immature detector. The process of generating the immature detectors is continued during all the "life" of SIS. This makes it possible to adapt the system to continuous changes of signatures. Immature detectors which passed the test become mature detectors.

The mature detectors participate in the identification of objects. To detect non-self objects, the mature detectors use detecting schemes (or matching rules) measuring a similarity between a detector and a signature of an unknown object. The lifetime of the mature detectors, like their immature counterparts, is not infinite. The mature detectors can also be eliminated. This can happen in two situations. First, when they are responsible for misclassification of a number of objects in turn. Second, once they are selected for a replacement. The replacement of the mature detectors with new immature detectors is performed periodically and it is necessary in order for the set of the mature detectors to include, all the time, up-to-date detectors. The detectors for replacement are selected at random, based on their lifetime, or based on frequency of detections performed by detectors. The simplified model of SIS is presented in Fig. 1.

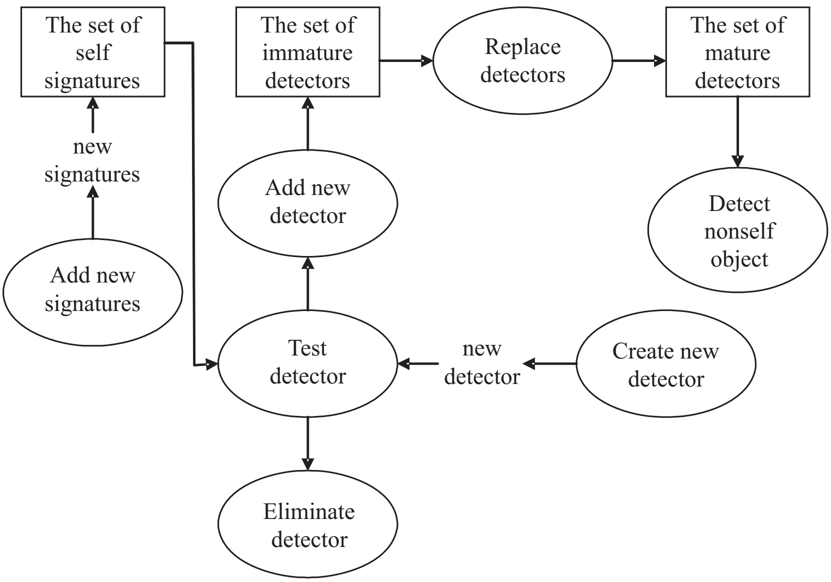

Fig. 1. Model of SIS

3. Vaccination in SIS

To sensitize SIS to definite signatures of non-self ships (vaccine signatures), appropriately constructed detectors have to be created (anti-vaccine detectors). The detectors are created at random but to form them, the signatures of non-self ships are used. To create anti-vaccine detectors, two methods can be applied. In the first vaccination method, the vaccine signatures with slight random perturbations play the role of the anti-vaccine detectors. In the second method, to create the anti-vaccine detectors, random perturbations are introduced not to the signatures of non-self ships but to regular detectors which detected the ships. Whereas in the first vaccination method the vaccine signatures are used as patterns to create the anti-vaccine detectors, in the second method the regular detectors sensitive to the vaccine signatures are used for the same purpose. In both methods, each anti-vaccine detector has to be put to the same test as the remaining detectors. Each of them has to be insensitive to all signatures of self ships. With regard to parameters of detectors, in the first method, the anti-vaccine detectors and the regular detectors can have the same parameters (r, δ, see further) but the solution in which both types of detectors have different parameters is also possible. In the second method, all detectors have the same parameters.

4. Experiments

The purpose of the experiments was to test effectiveness of the vaccination in SIS and to compare two vaccination methods described above. In the experiments, ships were represented by radio stations. Accordingly, the task of SIS was to differentiate self radio stations from non-self ones.

4.1. Variants of SIS used in the experiments

All variants of SIS tested in the experiments used detection scheme (1) (partial Euclidean distance):

$$\mathbf{x} M_r^{\delta} \mathbf{y} \Leftrightarrow \underset{i}{\exists} \quad d^E \left(\mathbf{x}[i,r], \mathbf{y}[i,r]\right) \leq \delta, \tag{1}$$

where: $\mathbf{x}$, $\mathbf{y}$ are the real valued vectors;
d^E is the Euclidean distance;
δ is the parameter;
$\mathbf{x} M^{\delta} \mathbf{y}$ means that the vectors $\mathbf{x}$, $\mathbf{y}$ match each other;
$\mathbf{x}[i, r]$ is the window of the size r included in the vector $\mathbf{x}$; the window begins from the position i.

Effectiveness of the scheme above was the main reason why it was used in all the experiments reported in the paper. It appeared to be the most effective detection scheme out of all schemes tested within the confines of the previous experiments [9]. Since, the scheme (1) achieved the best results for $r = 10$, the decision was made to use the same value in the current experiments. With regard to δ, the most effective value for this parameter was 0.6. For this reason, in all tested variants of SIS, except the variant with the first vaccination method, for all detectors the value

0.6 was used. In the variant with the first type of vaccination, different values of δ were applied for the anti-vaccine detectors and for the regular detectors. As for the value of δ for the anti-vaccine detectors, it was a parameter during the experiments. It was tuned so as to obtain possibly the best results. In the case of regular detectors, the value 0.6 was used.

In addition to the basic variant of SIS, in which a single detection is sufficient to find a ship non-self, in the experiments, a modification to this variant was also tested. The modification mentioned is an adaptation of *k*NN method and for that reason it was called *k*SIS. In *k*SIS, to detect a non-self ship, k separate detections are necessary. Generally, in the experiments, the following variants of SIS were tested:

- 1SIS — variant without vaccination and with $k = 1$;
- 2SIS — variant without vaccination and with $k = 2$;
- 4SIS — variant without vaccination and with $k = 4$;
- 1SIS_V1 — variant with the first vaccination method and with $k = 1$;
- 2SIS_V1 — variant with the first vaccination method and with $k = 2$;
- 4SIS_V1 — variant with the first vaccination method and with $k = 4$;
- 1SIS_V2 — variant with the second vaccination method and with $k = 1$;
- 2SIS_V2 — variant with the second vaccination method and with $k = 2$;
- 4SIS_V2 — variant with the second vaccination method and with $k = 4$.

All the variants were tested for a different number of detectors: 2000, 5000, or 10000 detectors (regular and anti-vaccine detectors). In variants with the vaccination, a different size of the vaccine was used: 10, 20, or 50 signatures of non-self ships introduced to the system. In the variant with the first vaccination method, five anti-vaccine detectors were generated for each signature from the vaccine. For example, for 10 vaccine signatures, 50 anti-vaccine detectors were produced. In the variant with the second vaccination method, a similar solution was applied. In this case, five detectors were created for each regular detector detecting a signature from the vaccine. This means that for each vaccine signature a different number of anti-vaccine detectors could be produced. Consequently, in both vaccination methods, we can deal with a different number of the regular and anti-vaccine detectors for the same size of the vaccine.

4.2. Radio signals

In the experiments, ships were represented in the form of encoded radio signals emitted by warship radio stations. Before the signals were used to represent the ships, first, they had been subjected to a feature extraction process. Initially, a discrete spectrum of each signal was fixed. To this end, a discrete Fast Fourier Transform (FFT) was used. Next, a central sample (S_c) of the most informative part of each spectrum was determined. In the following step, vectors including 600 samples to the left and 600 samples to the right from the central sample S_c were created. The vectors were then scaled to the range <0,1>. Since, vectors of size 1200 were still too long to represent ships in SIS (it was very difficult to generate random detectors of size 1200 that would be although slightly similar to any signature of a ship), they were further reduced in size to vectors including 100 samples. To generate vectors of size 100, different methods had been used in the previous experiments [9]. The most effective of them appeared to be the method in which ships were represented by means of the first hundred of samples extracted from the vectors of size 1200. The same method was used in the experiments reported in the current paper.

a) b)

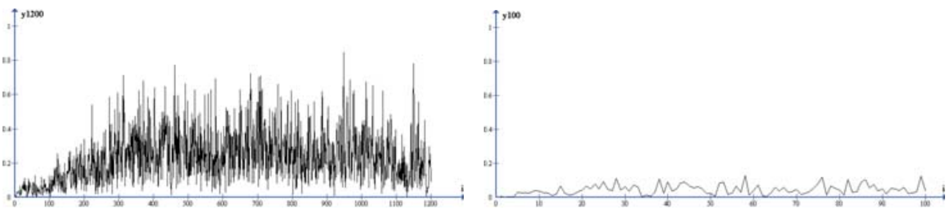

Fig. 2. (a) Exemplary signature of size 1200; (b) signature of size 100 generated from signature presented in point (a)

Generally, in the experiments, three sets of radio signals were used. The first set (set no. 1) contained 919 learning signals representing three self warships. It was used to prepare each method specified in the previous section. The next set (set no. 2) included 900 signals representing the same three self warships. The set was used to test all the methods. The last set (set no. 3) was composed of 667 signals generated by three warships considered to be non-self. This set was also used to test all the methods specified above.

4.3. Generating detectors

In the experiments, two detector generators were used. The task of the first generator was to create the anti-vaccine detectors. To this end, the generator mentioned added a random noise to a pattern vector which was a parameter of the generator. In the first vaccination method, randomly selected signatures of non-self ships played the role of pattern vectors. The second vaccination method used the regular detectors for the same purpose. The noise introduced to the pattern vectors was from the range <0, *max_noise*> and it was generated with the uniform distribution. *Max_noise* was a parameter of the generator. In the experiments, three values for this parameter were tested: 0.25, 0.1, and 0.05.

The task of the second generator was to form the regular detectors. In this case, the most effective generator from the previous experiments [9] was applied (Fig. 3). In all the experiments, the value 5 was used for the parameter of the generator.

```
genRegularDetector(int parameter)
{
for(int i=1;i<=d.length;i++)
      d[i]=(rand()%(parameter+1))/parameter;
}
```

Fig. 3. Generator used to create regular detectors

4.4. Experimental results

Thirty runs were performed for each method specified in section 4.1 and for each combination of parameters. The results summarizing all the experiments are

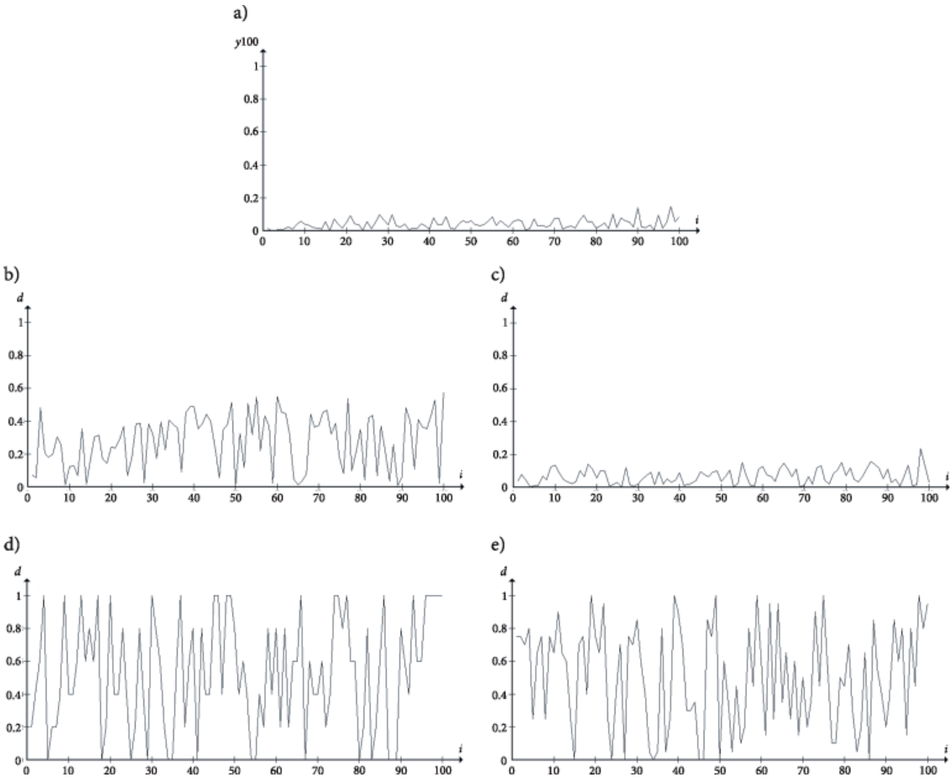

Fig. 4. (a) pattern signature of ship used to generate detectors presented in points (b), and (c); (b), (c) exemplary anti-vaccine detectors with different level of noise; (d), (e) exemplary regular detectors created by means of generator presented in Fig. 3

presented in Table 1. The table includes averaged results for the best configuration of each method. Generally, the experiments showed that the vaccination improves performance of SIS. In most cases, variants of SIS with the vaccination were more effective than variants without the vaccination. However, the improvement itself, regardless of the size of the vaccine, turned out to be rather insignificant. The best result with the vaccination was achieved by 4SIS_V2: 3.11% false positives, 29.39% false negatives, and 14.29% of all mistakes, on average. The best method without vaccination appeared to be 2SIS: 3.22% false positives, 31.18% false negatives, and 15.12% of all mistakes, on average. When comparing percent of all mistakes both methods differ only in one percent. It is rather a small difference.

Table 1

Results of experiments (methods are ordered according to the last column, i.e., from the best to the worst method; % of false positives — self form set no. 2 considered to be non-self; % of false negatives — non-self from set no. 3 considered to be self; % of all mistakes — wrong identifications of signals from set no. 2 and 3; δ_2 — value of δ for anti-vaccine detectors in the first vaccination method, value of δ for regular detectors was always equal to 0.6)

	% of false positives	% of false negatives	% of all mistakes	parameters
4SIS_V2	3.11%	29.39%	14.29%	$max\_noise = 0.25$
2SIS_V2	3.89%	28.94%	14.55%	$max\_noise = 0.1$
1SIS_V2	5.89%	26.99%	14.87%	$max\_noise = 0.25$
2SIS_V1	3.78%	30.13%	15.01%	$max\_noise = 0.05$, $\delta_2 = 0.05$
4SIS_V1	2.33%	32.23%	15.06%	$max\_noise = 0.1$, $\delta_2 = 0.09$
2SIS	3.22%	31.18%	15.12%	
4SIS	2.22%	33.88%	15.70%	
1SIS_V1	5.11%	31.33%	16.27%	$max\_noise = 0.1$, $\delta_2 = 0.09$
1SIS	3.56%	34.33%	16.66%	

With regard to the influence of the size of the vaccine results are somewhat confusing. In the case of the first vaccination method, it appeared that increase in the size of the vaccine causes the quality of detection to be worse (Fig. 5). The more signatures of non-self ships were known to the system, the worse the effectiveness of SIS was. It seems that the main cause of such situation is a close affinity between signatures of self and non-self ships. In the first vaccination method, the anti-vaccine detectors were generated from the vaccine signatures and, in consequence, they were very similar to them. As a result, even though their task was to detect non-self ships they also detected self ships of signatures close to signatures from the vaccine. The more the anti-vaccine detectors were generated from the vaccine signatures, the more false positives were observed. To reduce this effect, parameters δ for all the anti-vaccine detectors were set to much smaller values than in the case of the regular detectors. Thus, the area of responsibility of each anti-vaccine detector was very small. In consequence, each of them detected only signatures very close to it. Such solution reduced the number of false positives but at the same time it also led to decrease in the number of non-self ships detected by the anti-vaccine detectors. In most cases, they detected only signatures which were patterns for them.

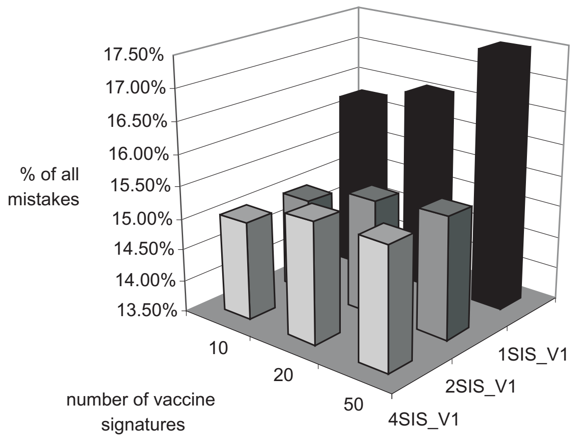

Fig. 5. The influence of the size of the vaccine on the effectiveness of SIS for the first vaccination method

In the case of the second vaccination method, increase in the size of the vaccine improves the quality of detection (Fig. 6). The main reason of such situation is constructing the anti-vaccine detectors based on the regular ones. In consequence, non-self ships are detected not from inside of the area with signatures, as it was before, but from far away. The anti-vaccine detectors surround signatures of self ships. Their area of activity does not include places inside concentrations of signatures and thereby they do not cause so many false positives as anti-vaccine detectors generated from the vaccine signatures. In this case, the number of the vaccine signatures affects only the accuracy of distinction between self and non-self ships. The more signatures are in the vaccine, the better division of the area with signatures into self and non-self is obtained.

With regard to the parameter *max_noise*, Table 1 shows that for the first vaccination method, smaller values for this parameter are more advantageous than the larger ones. The situation changes for the second vaccination method. In this case, larger values of *max_noise* are more effective. The explanation of this phenomenon is the same

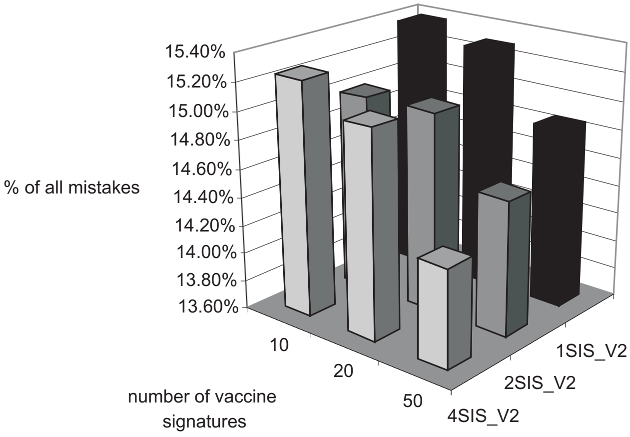

Fig. 6. The influence of the size of the vaccine on the effectiveness of SIS for the second vaccination method

as before. The anti-vaccine detectors generated from the vaccine signatures perform their task significantly better when their area of activity is narrowed and is situated close to their patterns. In the case of the anti-vaccine detectors created from the regular ones, a better solution is when their dispersal around their patterns is greater. Thus, they can cover greater areas around signatures of self ships.

The last observation from the experiments involves the ship identification itself. It appeared that efficient identification of ships exclusively based on radio signals is very difficult. The situation improves when signatures of non-self ships are introduced to SIS. However, a degree of the improvement is still unsatisfactory. Particularly important is to decrease the number of false negatives. The number of wrongly identified non-self ships is very large. In order for SIS to become effective tool for differentiating self and non-self ships the ability of the system to properly identify non-self ships has to be enhanced. Using many different ship representations (e.g. radar signals, sound generated by ship devices, magnetic field generated by ships; the previous experiments [9] had showed that extending radio signals to 1200 samples does not improve performance of SIS) may be a solution to this problem. Integer valued or binary detectors could be a next solution to the problem mentioned.

6. Summary

In the paper, the concept of SIS with the vaccination is presented. To test the concept mentioned, experiments were carried out. In the experiments, the task of SIS was to differentiate self warships from non-self ones. To represent warships, radio signals were used. In addition to SIS with the vaccination, for the comparison purposes, SIS without vaccination was also tested. The experiments showed that using the vaccination improves performance of SIS. In the experiments, it turned out that better vaccination method is to create anti-vaccine detectors, i.e., detectors being reaction of the system to a vaccine, based on other detectors than based on signatures of ships from a vaccine.

Since, results achieved by SIS with and without the vaccination seem to be still unsatisfactory, further experiments are planned. One of elements which can improve effectiveness of SIS is using extended representations of ships, i.e. radio signals, radar signals etc. A next element which can enhance performance of SIS is using detectors in the form of integer or binary strings. Such form of detectors is usually used in traditional models of AIS and for that reason it should also be tested in SIS.

Received April 15 2008, revised July 2009.

REFERENCES

[1] J. Balthrop, F. Esponda, S. Forrest, M. Glickman, *Coverage and Generalization in Artificial Immune System*, in Proc. Genetic Evolutionary Computation Conf., 2002.

[2] P. D'haeseleer, S. Forrest, P. Helman, *An Immunological Approach to Change Detection: Algorithms, Analysis and Implications*, Scientific Literature Digital Library, http://citeseer.ist.psu.edu

[3] F. Esponda, S. Forrest, P. Helman, *A Formal Framework for Positive and Negative Detection Schemes*, IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics, 34, 1, 2004, 357-373.

[4] R. Hightower, S. Forrest, A. Perelson, *The Baldwin Effect in the Immune System: Learning by Somatic Hypermutation*, in: R. K. Belew and M. Mitchell, editors, Individual Plasticity in Evolving Populations: Models and Algorithms, Addison-Wesley, 1996, 159-167.

[5] S. Hofmeyr, S. Forrest, A. Somayaji, *Intrusion Detection using Sequences of System Calls*, Scientific Literature Digital Library, http://citeseer.ist.psu.edu

[6] S. Forrest, S. Hofmeyr, *Immunology as Information Processing*, Design Principles for Immune Systems and Other Distributed Autonomous Systems, eds. Oxford Univ. Press, 2000, 361-387.

[7] T. Praczyk, *Adaptation of r-contiguous-bits scheme borrowed from immune systems to characteristic points of radar image identification*, Theoretical and Applied Informatics, vol. 19, 2007, 37-56.

[8] T. Praczyk, *The concept of the ship immune system*, Annual of Navigation (in press).

[9] T. Praczyk, *Using real valued detectors in Ship Immune System*, Computing and Informatics (in press).

[10] D. F. Specht, *Probabilistic neural networks*, Neural Networks, vol. 3, Issue 1, 1990, 109-118.

T. PRACZYK

Zastosowanie szczepienia w Okrętowym Systemie Immunologicznym

Streszczenie. Zadaniem okrętowego systemu immunologicznego jest rozróżnianie obiektów własnych, nie stanowiących zagrożenia dla okrętu, od obiektów obcych które mogą być dla niego groźne. Do realizacji powyższego zadania system wykorzystuje zbiór detektorów. Detektory imitują sygnatury

obiektów obcych, a do ich tworzenia wykorzystywane są sygnatury obiektów własnych zapamiętane w systemie. Ponieważ sygnatury obiektów obcych są zazwyczaj niedostępne, nie są one wykorzystywane w procesie tworzenia detektorów. Występują jednak sytuacje kiedy informacja o obiektach obcych jest dostępna podczas tworzenia systemu. Informacja ta może być wykorzystana do poprawienia jego efektywności. Artykuł przedstawia dwie metody umożliwiające wykorzystanie informacji o obiektach obcych podczas tworzenia detektorów. Obie metody zostały sprawdzone eksperymentalnie. Wyniki eksperymentów zostały przedstawione na końcu artykułu.
Słowa kluczowe: identyfikacja obiektów, sztuczny system immunologiczny
Symbole UKD: 007