Multi-sensor Fusion Applied to the Detection of Person-Borne Improvised Explosive Devices (PB-IEDs)

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Abstract— This paper describes the functionality of a sensor fusion toolbox designed to process data acquired by several state-of-the-art detection technologies during a trial on the detection of PB-IEDs, organized by TNO in 2016. The toolbox allows to define an operational scenario and determines successively the optimal combination of selected sensors which fulfills a number of given requirements.

1. INTRODUCTION

Suicide bombings in out of area missions, perpetrated either by Person-Borne Improvised Explosive Devices (PB-IEDs) or by (Suicide) Vehicle-Borne Improvised Explosive Devices ((S)VB-IEDs), represent one third of the IED attacks and have a large impact in terms of casualties for both military and civilians. PB-IEDs are often employed to make a political statement and to create chaos amongst the population. In order to decrease the impact of this type of IEDs, stand-off detection and neutralization is necessary. In the framework of the national research program on Countering IEDs, financed by the Netherlands MoD and with the support of the Defence Expertise Centre Counter-IED (DEC C-IED), TNO has assessed, by means of field measurements, the technological capabilities and limitations of state-of-the-art PB-IED detection technologies against realistic threats employed in military scenarios. The sensors are based on several technologies: millimeter wave imaging, radar technology, THz technology and infrared sensors [1].

Given a defined military scenario, i.e., compound protection, the detection performances of each sensor have been then combined in order to determine the optimal fusion of detection technologies that allows to improve the detection performances obtained with the single sensors. The sensor fusion has been carried out by means of a software toolbox, designed and developed by TNO. The toolbox allows to define new scenarios and requirements, and to calculate consequently the optimal combination of sensors that fulfil the requirements.

This paper is organized as follows. The trial is shortly described in Section 2, the sensor fusion methodology is described in Section 3 and the sensor fusion toolbox is presented in Section 4. The conclusions are presented in Section 5.

2. DESCRIPTION OF THE TRIAL

The trial has been held at TNO premises in 2016. Several state-of-the-art detection technologies have been tested against four military scenarios, where realistic threats were employed. The data acquired by the single sensors has been processed in a sensor fusion toolbox, with the aim to determine, for a given realistic military scenario, what is the optimal sensor combination that improves the overall system of systems detection performances. An example of a military scenario, including realistic threats and a list of detection technologies, is described hereafter.

2.1. Military Scenario: Compound Protection

Compound protection against PB-IEDs aims at identifying an imminent threat at a safe distance from the compound and in any case, before the threat enters the compound. The scenario is sketched in Figure 1. Several people, walking alone or in small groups, are approaching the compound. These people are screened with outdoor detection systems, which can detect PB-IEDs at larger stand-off distances, and with detection systems that operate at shorter stand-off distances. A combination of sensors has to fulfill a number of operational requirements. For instance, it may be required to detect all the threats of the data set, or it may be required to allow an high throughput at rush hours, or very large stand-off distances may be required, etc.

Possible threats are IEDs concealed beneath few layers of clothing. The PB-IEDs may or may not contain shrapnel. An example of a PB-IED concealed in a vest is shown in Figure 2.

The detection technologies that can be used to detect a suicide bomber can be both active and/or passive systems. The detection systems used in the trial are based on various technologies: radar and millimetre wave scanners, passive THz video camera, passive IR camera and Raman

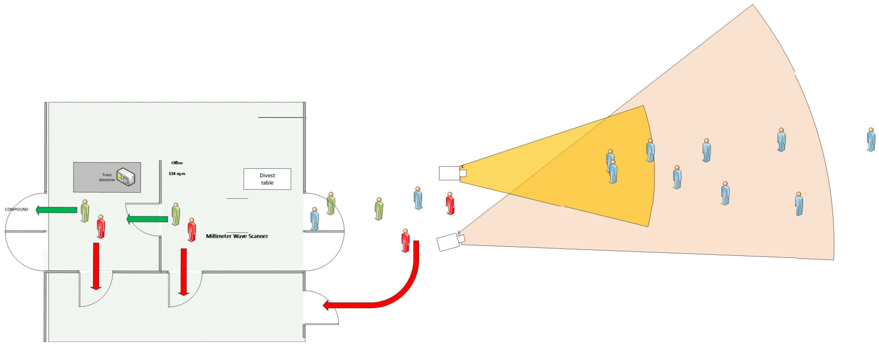


Figure 1: Sketch of the military scenario compound protection.

Figure 2: Detail of the explosives concealed in a vest.

system for detection and identification of traces of explosive materials. Some of the scanners were provided with Automatic Target Recognition (ATR).

3. SENSOR FUSION METHODOLOGY

Sensor fusion can be implemented at various stages of the detection chain. The data collected during the trial allows to apply sensor fusion only at the last stage of the detection chain of each single sensor. Hence, only the detection result (if a possible IED is detected) of a sensor is available for fusion.

A list of sensor fusion methods applicable to the data is given hereafter:

1. Confirmation of a threat (AND)

   The AND fusion method performs a confirmation of threat detections. In other words: if (and only if) all the selected sensors detect a threat, the detection is used as a result of the fusion process.

2. Complementary systems (OR)

   The OR fusion method is a function of the systems complementarity. In other words: if any of the selected sensors detects a threat, the detection is used as a result of the fusion process.

3. Cascade (combination of AND and OR)

   The Cascade fusion methods perform fusion in two steps. The set of sensors is divided in two or more subsets. For instance, the stand-off distance can be used as parameter to create the subsets. Sensor fusion is then applied to each subset of sensors and then the sensor fusion is applied to the outputs of the first stage. There are two implementations for the Cascade method available. The first one consists in applying the operation ((OR)AND(OR)), which corresponds to a combined confirmation; the second one consists in applying the operation ((AND)OR(AND)), which corresponds to a combined complementarity of more than 2 systems.

4. Majority

The Majority fusion method performs a confirmation of threat detections based on a majority vote. In other words: if (and only if) more than half of the sensors agree on a threat detection, the detection is used as a result of the fusion process.

4. SENSOR FUSION TOOLBOX

The toolbox is written in Python 3 and tested in the WinPython-64bit-3.6.2.0Qt5 distribution. The toolbox is a web application based on the Flask framework. The used Flask version is 0.12.2. The main window of the toolbox is shown in Figure 3. The toolbox allows to define a specific scenario, by selecting threat types, detection technologies, mock description, clothing type. Once the scenario has been defined, it is either possible to select a sensor fusion method, or to let the toolbox calculate all the possible sensor fusions results.

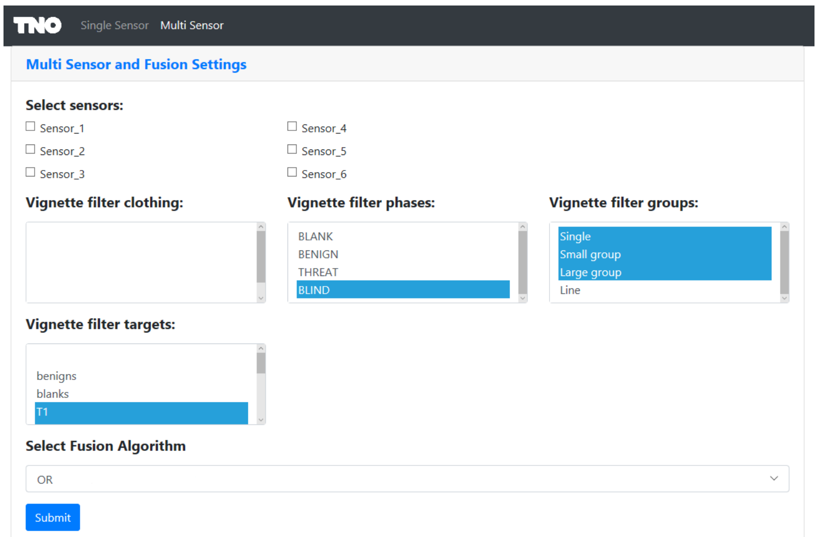


Figure 3: Main window of the sensor fusion toolbox.

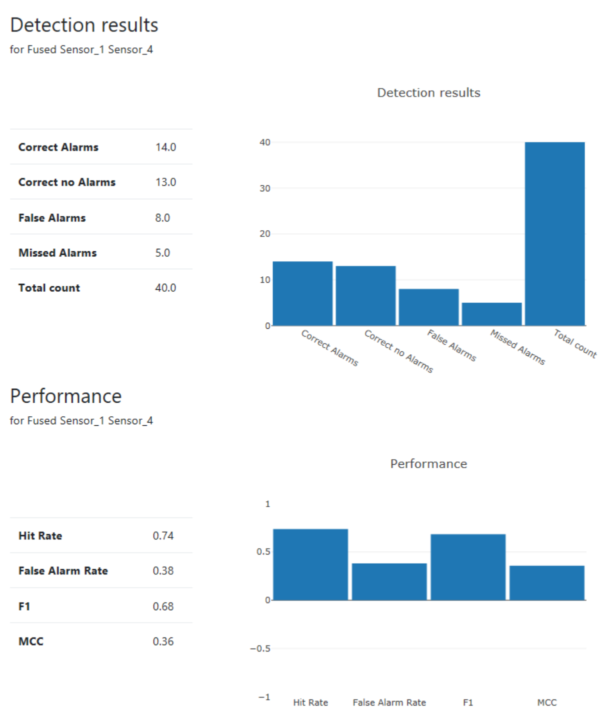
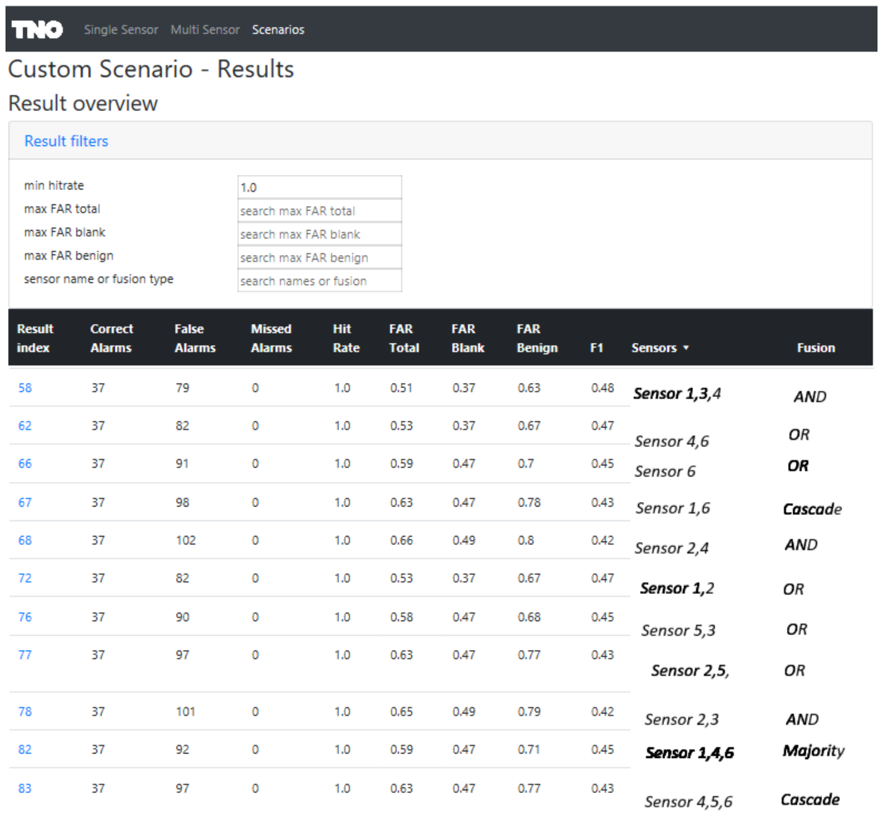


Figure 4: Example of detection performances of a sensor fusion.

Figure 4 shows an example of a detection performance resulted from the combination of two sensors when the complementary sensor fusion method is selected. The detection performances include the detection rate (Hit Rate in the figure), the false alarm rate and two sensor fusion parameters, F1 and MCC. The F1 and MCC (Matthews correlation coefficient) score are used as measures of the quality of binary (two-class) classifications. Both scores can be derived from the confusion matrix. In the case of a binary classification, the confusion matrix is a two by two table visualizing the performance of an algorithm [2].

Figure 5 shows an example of a list of results of possible combinations of sensors, including the sensor fusion method used. The list includes the detection performances of the combination of systems and in addition the F1 score. The optimal combination is chosen based on the highest F1 score. Please notice that the list shown in the figure is a subset of results, since an additional filter allows the user to refine the results. The situation showed in the figure represents the case in which all the threats under test are detected.


TNO Single Sensor Multi Sensor Scenarios

Custom Scenario - Results

Result overview

Result filters

min hitrate: 1.0
max FAR total: search max FAR total
max FAR blank: search max FAR blank
max FAR benign: search max FAR benign
sensor name or fusion type: search names or fusion

Result index	Correct Alarms	False Alarms	Missed Alarms	Hit Rate	FAR Total	FAR Blank	FAR Benign	F1	Sensors ▾	Fusion
58	37	79	0	1.0	0.51	0.37	0.63	0.48	Sensor 1,3,4	AND
62	37	82	0	1.0	0.53	0.37	0.67	0.47	Sensor 4,6	OR
66	37	91	0	1.0	0.59	0.47	0.7	0.45	Sensor 6	OR
67	37	98	0	1.0	0.63	0.47	0.78	0.43	Sensor 1,6	Cascade
68	37	102	0	1.0	0.66	0.49	0.8	0.42	Sensor 2,4	AND
72	37	82	0	1.0	0.53	0.37	0.67	0.47	Sensor 1,2	OR
76	37	90	0	1.0	0.58	0.47	0.68	0.45	Sensor 5,3	OR
77	37	97	0	1.0	0.63	0.47	0.77	0.43	Sensor 2,5,	OR
78	37	101	0	1.0	0.65	0.49	0.79	0.42	Sensor 2,3	AND
82	37	92	0	1.0	0.59	0.47	0.71	0.45	Sensor 1,4,6	Majority
83	37	97	0	1.0	0.63	0.47	0.77	0.43	Sensor 4,5,6	Cascade

Figure 5: Example of a list of a scenario based sensor fusion results.

5. CONCLUSION

This paper has presented the sensor fusion toolbox developed at TNO in order to process the data collected during a trial in the framework of a project on detection of PB-IEDs. The software toolbox allows to define scenarios (types of sensors, types of threats, mock and clothing) and requirements and to calculate consequently the optimal combination of sensors that fulfill the given requirements. The toolbox is dynamic, in the sense that it is possible to filter the data in various ways, allowing an operator to understand better how to combine different sensors.

The sensor fusion methods presented here have been applied at the last stage of the detection chain: each sensor has taken a decision based only on its own data. Sensor fusion methods applied at earlier stages of the detection chain allow the sensors to use additional information and will eventually help to improve the detection performances. This process, however, requires collaboration of the sensors during sensor fusion, i.e., sharing pre-processed data. This research towards a pre-detection sensor fusion system architecture for PB-IEDs will be investigated in the framework of a NATO-STO Exploratory Team in 2019, led by TNO [3].

ACKNOWLEDGMENT

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