An Evaluation of the MoTron TxID-1 Transmitter Fingerprinting System

by

N. Serinken, K.J. Ellis, E.L. Lavigne

Communications Research Centre
3701 Carling Ave.
Ottawa, Ontario
K2H 8S2

February, 1997

Table of Contents

Abstract

With an increased public demand for a greater number of wireless communication systems has come the problem of safeguarding this valuable spectrum from abuses by individuals whose intent is to either cause interference to, or steal services from its licensed occupants. Unfortunately, this problem has been compounded by the fact that the criminal and malicious elements have become increasingly more sophisticated and have ready access to advanced communications equipment.

The MoTron TxID-1 transmitter fingerprinting system is currently the only system used by spectrum management personnel in Canada and the United States for the purpose of identifying unlawfully operated transmitters. A performance analysis of this system under controlled operating conditions has shown that this simple low-cost system is quite effective at identifying individual transmitters under controlled conditions.

1.0 Introduction

The MoTron TxID-1 transmitter identification system has been used by spectrum management personnel at both Industry Canada and the US Federal Communications Commission (FCC) to aid in the identification of emissions from illegally operated two-way radio transmitters. While this system has been used for a number of years, there appears to be an absence of information characterizing its overall effectiveness. In this report, the TxID system is evaluated in terms of its ability to correctly identify emissions from a variety of transmitters. By carrying out this evaluation under controlled conditions the reliability of the TxID-1 is determined for the purpose of establishing a benchmark to which the performance of other transmitter fingerprinting systems can be referenced. While it is acknowledged that the range of conditions routinely encountered in "real world" fingerprinting operations are not reflected in this evaluation, it is important to note that the fundamental objective of this work was to evaluate the performance of this system under favorable conditions. In the sections that follow, the procedures, performance measures and experimental results used in this assessment are presented.

2.0 The TxID-1 System

The heart of the TxID-1 system is a circuit board which mounts inside a personal computer (PC). Contained on this board are all the components required to allow its on-board processor to interact with its host PC and to acquire fingerprints from a communications receiver. When triggered by a turn-on transient, signals from the receiver's FM discriminator circuit - which represent the transmitter's fingerprint - are sampled, displayed on the computer screen and then written to disk. Unfortunately, discriminator outputs are not usually provided by the manufacturer and consequently many receivers must be modified before they can be used with the TxID-1 system.

Using the companion software, a program called CLOSEST, fingerprints from an unknown transmitter can be compared with those of "known" transmitters for identification purposes. These comparisons are made by computing the mean square difference (MSD) between the "known" and "unknown" prints. Low MSD values indicate a high degree of similarity between two prints while high MSD values signify a poorer match. The final decision as to whether or not the MSD value does in fact indicate a positive match, is left to the operator's discretion.

3.0 Experimental Setup

To assess the overall reliability of the TxID-1 transmitter fingerprinting system a number of prints from a variety of VHF FM transmitters were collected. In this study, a total of 11 radios were tested: five of these were high-power mobile units and the remaining six were low-power portable units. A summary listing the make, model, serial number and output power level of each of these radios is presented in Table 1. All transmitters were phase-locked-loop (PLL) controlled and were operated at a frequency of 147.775 MHz. A sample consisting of 55 fingerprints was collected from each of these radios. The first 5 from each sample were selected to serve as reference or "known" prints while the remaining 50 were used as "unknown" prints for evaluation purposes. It should be noted that the power levels quoted in Table 1 were measured by coupling the
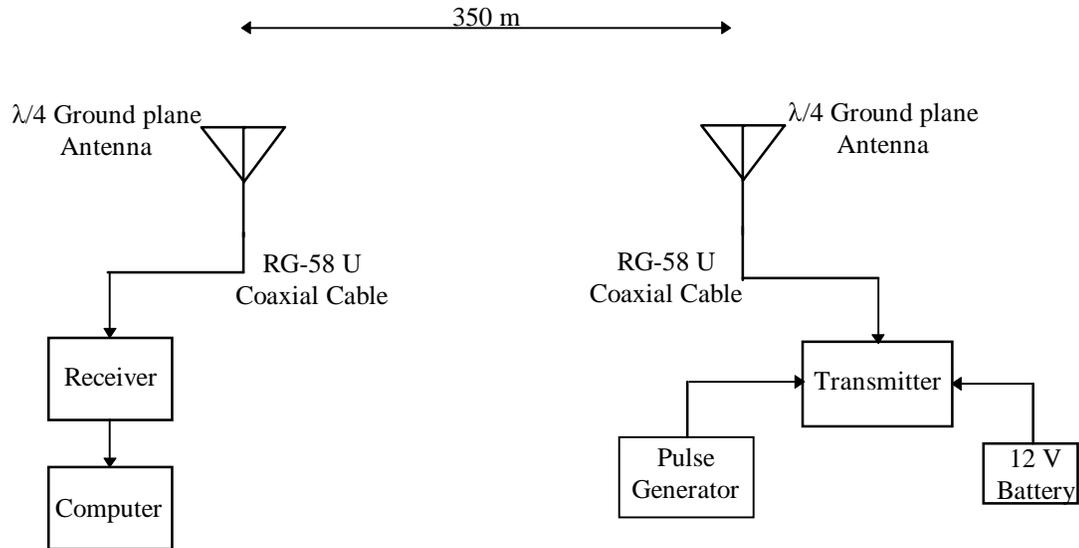
Figure 1 Experimental setup

transmitter outputs to a spectrum analyzer through a series of attenuators and a 27 m length of coaxial cable.

The transmitters used in this experiment were installed in a vehicle located approximately 350 m away from the receiving location as illustrated in Figure 1. In all cases, these transmitters were connected to a λ/4 ground plane antenna mounted at a height of 3.66 m and powered from a 12 V deep-cycle marine battery. A 15.24 m length of RG-58U coaxial cable was used to connect this antenna to each of the transmitters. To mitigate any possible thermal effects which could affect fingerprint consistency, a heater was placed in the vehicle to maintain an ambient temperature of approximately 14° C. The need for a human operator to key these transmitters was eliminated by using a pulse generator and relay arrangement to automatically control the push-to-talk (PTT) lines of each radio. Using this setup, test transmissions approximately 0.5 seconds in duration were repeated at 1.0 second intervals i.e. transmitter on for 0.5 s and then off for the next 0.5 s. It should be noted that all portable radios were fingerprinted at their low power setting.

At the receiving location, an Icom R7100 receiver, TxID-1 board and 386 computer were used to capture and record the fingerprints from each transmitter. A λ/4 ground-plane antenna, identical to that employed at the transmitter, was also used at the receiving site. This antenna was also mounted at a height of 3.66 m and was connected to the receiver through a 30.48 m length of RG-58U coaxial cable. To ensure that the received power levels from each of the transmitters were roughly equal, the receiver's internal 20 dB attenuator was activated when the high power mobile transmitters were in use.

Table 1 Transmitter summary

T_x Name	Model	Serial Number	Pwr. (W)
Motorola1	MCX100	484PGU4192	28.0
Motorola3	MCX100	484PGU4191	27.0
Force1	CMH350	13000675	35.0
Force2	CMH350	13000676	33.0
Force3	CMH350	13000674	34.0
Kenwood1	TH25AT	9080861	0.10
Kenwood2	TH25AT	9080901	0.20
Kenwood3	TH25AT	9080840	0.23
Kenwood4	TH21AT	5056533	0.08
Yaesu1	FT208R	2K210164	0.81
Yaesu2	FT208R	-	0.17

4.0 Performance Measures and Experimental Results

To gain insight into the behavior of the MSD measure used by the TxID system, the statistics describing the magnitude of this quantity were computed under both "matched" and "unmatched" conditions. In this work, the matched condition exists when a radio fingerprint is compared with prints contained in the "known" data set for the same transmitter while the unmatched condition exists when a radio fingerprint is compared with those prints contained in the "known" data sets for other transmitters. The probability measures describing the overall statistics for all fingerprints under matched and unmatched conditions are P_{Mo} and P_{Uo} respectively, and are given by:

$$P_{Mo} = P_r\left(MSD \leq Threshold\right) = \frac{\sum_{i=1}^{W} N_{Mi}}{\sum_{i=1}^{W} N_i} \tag{1}$$

and

$$P_{Uo} = P_r\left(MSD \leq Threshold\right) = \frac{\sum_{i=1}^{W} \sum_{j=1, j\neq i}^{W} N_{Uij}}{\sum_{i=1}^{W} \sum_{j=1, j\neq i}^{W} N_{ij}} \tag{2}$$

where; N_{Mi} represents the number of fingerprints from the ith transmitter which, when compared with "known" prints from the same transmitter, produced MSD values below the given threshold, N_{Uij} represents the number of fingerprints from the ith transmitter which, when compared with "known" fingerprints from the jth transmitter, produced MSD values below the given threshold, N_i is the number of fingerprints considered in the comparisons with the "known" prints for the ith transmitter, N_{ij} is the number of fingerprints from the ith transmitter that are compared with the known prints for the jth transmitter and W represents the total number of transmitters under consideration.

Using the experimental data, the matched and unmatched probabilities (P_{Mo} and P_{Uo}) were computed as a function of the MSD for threshold levels ranging from 0 to 2000 which correspond to the minimum and maximum values returned by the CLOSEST algorithm. Intuitively, one would expect the "matched" probability, P_{Mo} to be small for low MSD thresholds due to the fact that very few fingerprint comparisons would result in near zero values. As the threshold level is increased, one would anticipate a rapid increase in this probability since a growing number of print comparisons would be expected to produce a greater number of MSD values below the given threshold. On the other hand, the "unmatched" probability, would also be expected to start out near zero - but for the reason that very few comparisons of dissimilar prints would be expected to produce small MSD values. As the threshold value is increased, a higher unmatched probability would be anticipated as a greater number of dissimilar fingerprints would begin to produce MSDs falling within the expanding range of values below the current threshold level. The results of such an analysis are shown in the two curves plotted in Figure 2 which plainly demonstrate the expected trends. Under matched conditions, the probabilities that small MSDs are generated are 0.90, 0.85 and 0.81 for thresholds of 71, 38 and 15 respectively, while under unmatched conditions, the probabilities that small MSDs are returned are reduced to 0.15, 0.09 and 0.05 respectively for the same threshold settings. It should be noted that although not shown in the Figure, the curves for both P_{Mo} and P_{Uo} reach unity at an MSD threshold of 2000.
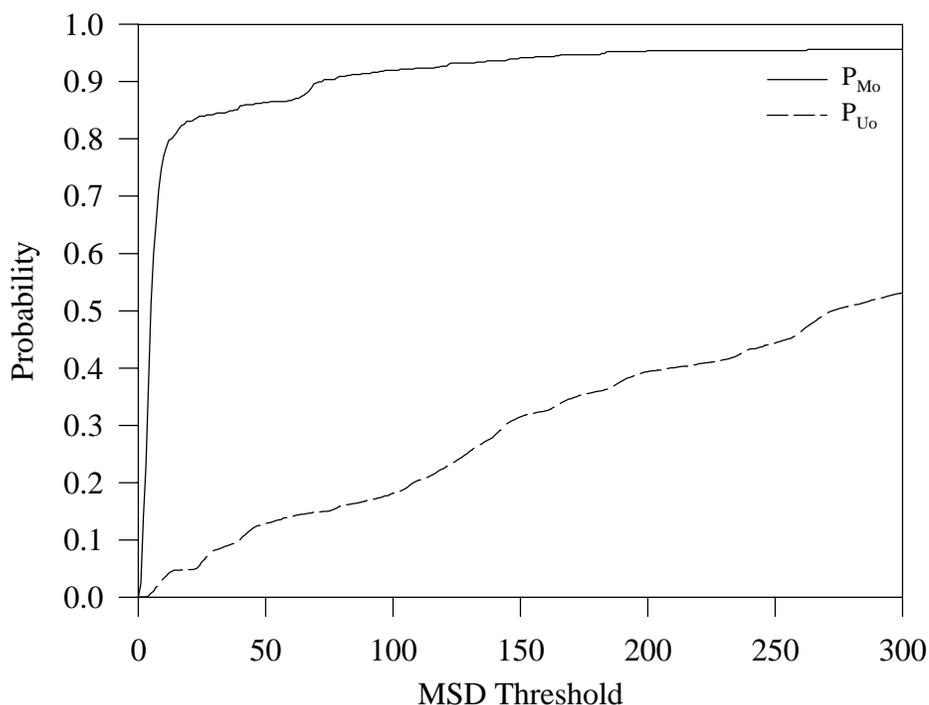

Figure 2 Fingerprint statistics under matched and unmatched conditions

Of particular interest in this evaluation, however, is the ability of this system to correctly identify the emissions from a group of transmitters. In the analysis that follows, the ability to reliably identify fingerprints from a particular transmitter is assessed in terms of the

overall probabilities of correct and false identification which are denoted by P_{co} and P_{fo} respectively. A correct identification occurs when all of the following conditions are satisfied:

(i)   The fingerprint under consideration, when compared with the "known" prints from   all other transmitters, produces the lowest MSD when compared with its own "known" prints.

(ii)   The lowest MSD value is unique.

(iii)   The lowest MSD value is less than or equal to the specified threshold level.

Conversely, a false identification occurs when a fingerprint fails to meet these criteria. The identification probabilities P_{co} and P_{fo} are defined here as:

$$P_{co} = P_r\left(MSD \leq Threshold\right) = \frac{\sum_{i=1}^{W} N_{ci}}{\sum_{i=1}^{W} N_i} \qquad (3)$$

and

$$P_{fo} = 1 - P_{co} \qquad (4)$$

where; N_i and N_{ci} represent the number of fingerprints under consideration and the number of correct identifications made (according to the decision rules) for the ith transmitter respectively.

Applying these measures to the data, one obtains the results shown in Figure 3. From this graph it is clear that in order to achieve a correct identification probability near 0.80, an MSD threshold greater than 13 must be selected. Beyond this level, P_{co} and P_{fo} change very slowly and achieve final values of approximately 0.91 and 0.09 respectively at thresholds greater than 263. Above this level, P_{co} and P_{fo} are essentially independent of the MSD threshold, and consequently, the decision rule can be simplified such that one need only choose the transmitter producing the lowest MSD of all transmitters in the group. While adopting such a rule will yield the performance results given in Figure 3, it should be noted that if the pool of "known" prints does not contain those of the transmitter in question, all identifications involving these prints will be in error as the lowest MSD value will correspond to a transmitter other than the one under consideration. As this case represents a realistic scenario, which could typically arise when checking a fingerprint database to determine if a series of prints had been previously recorded, additional measures must be employed if the identification reliability is to be maintained.

Fortunately, the false identification probability for this particular case can be estimated conservatively using the "unmatched" probability, P_{Uo}, introduced at the beginning of this section. According to these statistics, the probability of making a false
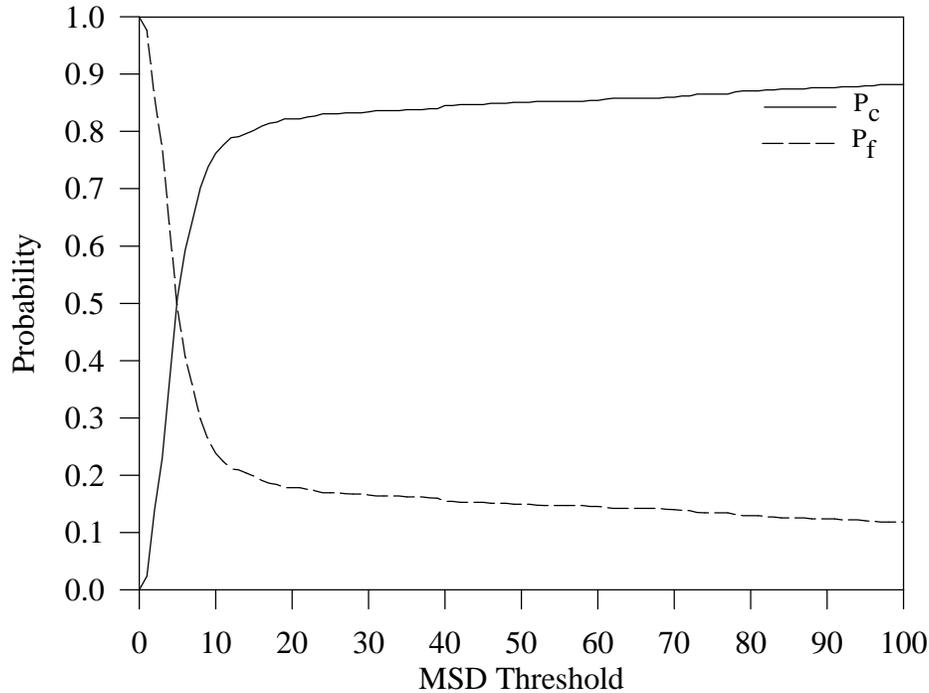
Figure 3 Probabilities of correct and false identification

identification when the fingerprint in question is not within the pool of "known" prints, can be held to acceptable levels by simply imposing a suitable MSD threshold. Several practical threshold settings and their corresponding reliability figures are given in Table 2. From these value, reasonably good performance can be obtained by selecting a threshold level of 71, which gives a 0.86 probability of correct identification and nearly equal probabilities of false identification under matched and unmatched conditions.

Table 2 Threshold and reliability values

MSD Threshold	P_{co}	P_{fo}	P_{Uo}
15	0.80	0.20	0.05
38	0.84	0.16	0.09
71	0.86	0.14	0.15

An additional characteristic of interest in this study was the consistency of the fingerprints generated by each of the transmitters. Using the same data set from which the performance measures were originally obtained, the standard deviation of the MSD values for the fingerprint ensemble from a given radio was computed. The results of this analysis are presented in Table 3. Intuitively, one would expect that if the fingerprints produced by each of the radios were in fact consistent, then the variance of the MSD values should be relatively small. Unfortunately it is unclear at this time if the larger standard deviations associated with certain radios arise from the actual construction of the equipment or are the result of some other unidentified process.

Table 3 Fingerprint consistency measurements

Transmitter	Std. Deviation	Transmitter	Std. Deviation
Force #1	1.159	Kenwood #4	52.458
Force #2	27.206	Motorola #1	1.110
Force #3	29.575	Motorola #3	1.042
Kenwood #1	1.939	Yaesu #1	572.246
Kenwood #2	8.707	Yaesu #2	257.721
Kenwood #3	71.680	-	-

5.0 System Limitations

One drawback of the MoTron approach is that many commercially available receivers do not possess a discriminator output and consequently must be modified in order to be used with the TxID-1 system. Coupled with this limitation is the fact that receivers cannot be easily substituted unless several resistor values on the TxID-1 board are altered. Because the board is effectively "matched" to a given receiver and since differences are encountered between receivers, even among those of the same model, fingerprints taken with one system cannot be compared with those recorded on another. This means that a central database of transmitter fingerprints cannot be established and used by multiple monitoring stations for intercept identification.

Although the procedures indicated in the operator's manual suggest that the system need only be adjusted upon installation, it was found that the on-board variable resistor, VR1, required occasional adjustment to permit the system to correctly record transients. It was also found that some additional tweaking was required to both centre the fingerprint in the on-screen graticule and to get the TxID-1 board to work properly inside a high-speed computer. In general, a more detailed operator's manual would have been beneficial.

In addition to the issues already discussed, two software limitations were identified during the course of this evaluation. The first of these was the absence of an edit facility in the "TXID" program dated July 22, 1993 that would allow the user to delete selected fingerprints from within a given file. A second and more significant limitation was that the "CLOSEST" program of June 30, 1994 could not automatically perform the function of transmitter identification.

6.0 Conclusions

In spite of the detractors outlined in the previous section, the results of this evaluation have shown the TxID-1 system to be a practical and effective means by which transmitter fingerprints can be captured and identified. It should be stressed, however, that the performance results presented in this report may not adequately characterize the capabilities of this system under conditions other than those in which these tests were conducted. As such, engineering judgment must be exercised if these reliability results are to be used as a benchmark to which the performance of other fingerprinting systems are referred.

Acknowledgments

The authors would like to thank Mr. R. Jackman and Mr. G. Ritchie from Industry Canada, RSSC Acton for their many good suggestions and technical advice that aided us in completing this work.

References

[1]   MoTron Electronics, "TxID-1: Transmitter FingerPrinting System Operation and Installation Manual", 310 Garfield Street, Suite 4, Eugene, Oregon 97402.