National College of Ireland

Configuration Manual

MSc Research Project
Cyber Security

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National College of Ireland

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MSc Project Submission Sheet

School of Computing

Student Name: Siddharth Sankar

Student ID: 23418541

Programme: MSc Cyber Security **Year:** 2025

Module: MSc Research Project

Supervisor: Niall Heffernan

Submission Due Date: 28/01/2026

Project Title: Continuous User Authentication on Mobile and Desktop Devices using Behavioural Biometrics – a Multimodal Approach

Word Count: **198** **Page Count 8**

I hereby certify that the information contained in this (my submission) is information pertaining to research I conducted for this project. All information other than my own contribution will be fully referenced and listed in the relevant bibliography section at the rear of the project.
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Signature: Siddharth Sankar

Date: 27/01/2026

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Configuration Manual

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1 System Requirements

The project was intentionally kept lightweight so that it could be easily replicated. Here is the ideal setup to replicate the implementation:

1.1 Hardware Used

A Dell Inspiron laptop with the following specifications:

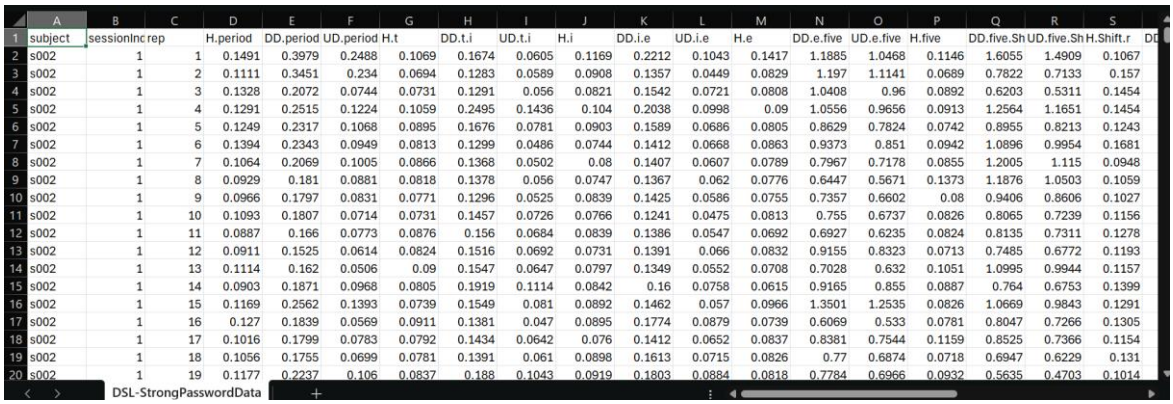
- 16GB RAM
- 11th Gen Intel (R) Core™ i7-11370H @ 3.30 GHz Processor
- Storage 256GB
- Windows 11 Operating System

1.2 Software Used

- Environment: Google Colab (can be implemented locally using Jupiter Notebook as Well)
- Language: Python 3.9
- Libraries: Pandas, Numpy, Scikit-Learn, Matplotlib, Seaborn and ScipPy were used.
- Browser: Brave

2 Data Handling

2.1 Desktop Dataset

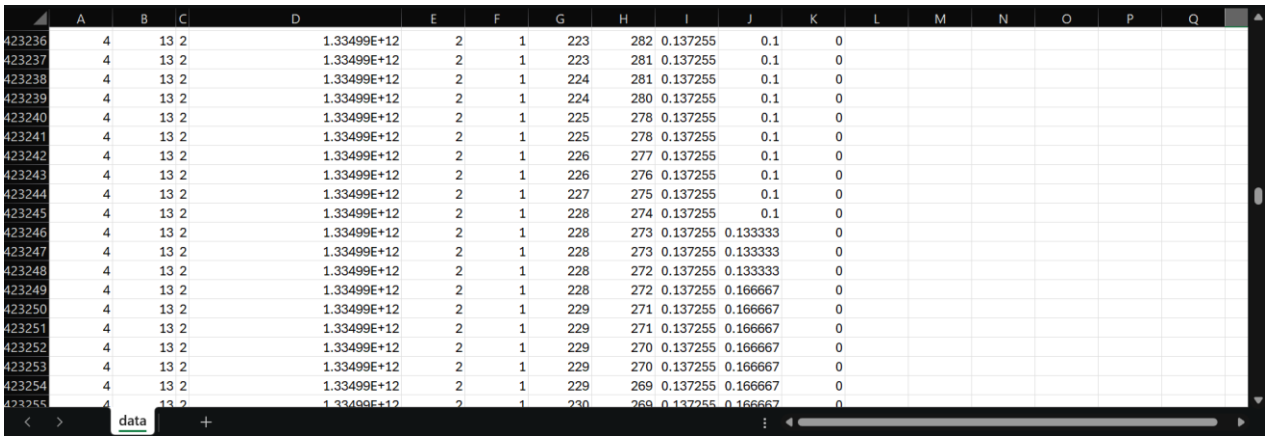


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	subject	sessionInc	rep	H.period	DD.period	UD.period	H.t	DD.t.i	UD.t.i	H.i	DD.i.e	UD.i.e	H.e	DD.e.five	UD.e.five	H.five	DD.five.Sh	UD.five.Sh	H.Shift.r
2	s002	1	1	0.1491	0.3979	0.2488	0.1069	0.1674	0.0605	0.1169	0.2212	0.1043	0.1417	1.1885	1.0468	0.1146	1.6055	1.4909	0.1067
3	s002	1	2	0.1111	0.3451	0.234	0.0694	0.1283	0.0589	0.0908	0.1357	0.0449	0.0829	1.197	1.1141	0.0689	0.7822	0.7133	0.157
4	s002	1	3	0.1328	0.2072	0.0744	0.0731	0.1291	0.056	0.0821	0.1542	0.0721	0.0808	1.0408	0.96	0.0892	0.6203	0.5311	0.1454
5	s002	1	4	0.1291	0.2515	0.1224	0.1059	0.2495	0.1436	0.104	0.2038	0.0998	0.09	1.0556	0.9656	0.0913	1.2564	1.1651	0.1454
6	s002	1	5	0.1249	0.2317	0.1068	0.0895	0.1676	0.0781	0.0903	0.1589	0.0686	0.0805	0.8629	0.7824	0.0742	0.8955	0.8213	0.1243
7	s002	1	6	0.1394	0.2343	0.0949	0.0813	0.1299	0.0486	0.0744	0.1412	0.0668	0.0863	0.9373	0.851	0.0942	1.0896	0.9954	0.1681
8	s002	1	7	0.1064	0.2069	0.1005	0.0866	0.1368	0.0502	0.08	0.1407	0.0607	0.0789	0.7967	0.7178	0.0855	1.2005	1.115	0.0948
9	s002	1	8	0.0929	0.181	0.0881	0.0818	0.1378	0.056	0.0747	0.1367	0.062	0.0776	0.6447	0.5671	0.1373	1.1876	1.0503	0.1059
10	s002	1	9	0.0966	0.1797	0.0831	0.0771	0.1296	0.0525	0.0839	0.1425	0.0586	0.0755	0.7357	0.6602	0.08	0.9406	0.8606	0.1027
11	s002	1	10	0.1093	0.1807	0.0714	0.0731	0.1457	0.0726	0.0766	0.1241	0.0475	0.0813	0.755	0.6737	0.0826	0.8065	0.7239	0.1156
12	s002	1	11	0.0887	0.166	0.0773	0.0876	0.156	0.0684	0.0839	0.1386	0.0547	0.0692	0.6927	0.6235	0.0824	0.8135	0.7311	0.1278
13	s002	1	12	0.0911	0.1525	0.0614	0.0824	0.1516	0.0692	0.0731	0.1391	0.066	0.0832	0.9155	0.8323	0.0713	0.7485	0.6772	0.1193
14	s002	1	13	0.1114	0.162	0.0506	0.09	0.1547	0.0647	0.0797	0.1349	0.0552	0.0708	0.7028	0.632	0.1051	1.0995	0.9944	0.1157
15	s002	1	14	0.0903	0.1871	0.0968	0.0805	0.1919	0.1114	0.0842	0.16	0.0758	0.0615	0.9165	0.855	0.0887	0.764	0.6753	0.1399
16	s002	1	15	0.1169	0.2562	0.1393	0.0739	0.1549	0.081	0.0892	0.1462	0.057	0.0966	1.3501	1.2535	0.0826	1.0669	0.9843	0.1291
17	s002	1	16	0.127	0.1839	0.0569	0.0911	0.1381	0.047	0.0895	0.1774	0.0879	0.0739	0.6069	0.533	0.0781	0.8047	0.7266	0.1305
18	s002	1	17	0.1016	0.1799	0.0783	0.0792	0.1434	0.0642	0.076	0.1412	0.0652	0.0837	0.8381	0.7544	0.1159	0.8525	0.7366	0.1154
19	s002	1	18	0.1056	0.1755	0.0699	0.0781	0.1391	0.061	0.0898	0.1613	0.0715	0.0826	0.77	0.6874	0.0718	0.6947	0.6229	0.131
20	s002	1	19	0.1177	0.2237	0.106	0.0837	0.188	0.1043	0.0919	0.1803	0.0884	0.0818	0.7784	0.6966	0.0932	0.5635	0.4703	0.1014

DSL-StrongPasswordData

Source: https://www.cs.cmu.edu/~keystroke/#sec2
Configuration: Download the Csv file and upload it onto Colab File System

2.2 Mobile Dataset (TouchAnalytics)



	A	B	C	D	E	F	G	H	I	J	K
423236	4	13	2	1.33499E+12	2	1	223	282	0.137255	0.1	0
423237	4	13	2	1.33499E+12	2	1	223	281	0.137255	0.1	0
423238	4	13	2	1.33499E+12	2	1	224	281	0.137255	0.1	0
423239	4	13	2	1.33499E+12	2	1	224	280	0.137255	0.1	0
423240	4	13	2	1.33499E+12	2	1	225	278	0.137255	0.1	0
423241	4	13	2	1.33499E+12	2	1	225	278	0.137255	0.1	0
423242	4	13	2	1.33499E+12	2	1	226	277	0.137255	0.1	0
423243	4	13	2	1.33499E+12	2	1	226	276	0.137255	0.1	0
423244	4	13	2	1.33499E+12	2	1	227	275	0.137255	0.1	0
423245	4	13	2	1.33499E+12	2	1	228	274	0.137255	0.1	0
423246	4	13	2	1.33499E+12	2	1	228	273	0.137255	0.133333	0
423247	4	13	2	1.33499E+12	2	1	228	273	0.137255	0.133333	0
423248	4	13	2	1.33499E+12	2	1	228	272	0.137255	0.133333	0
423249	4	13	2	1.33499E+12	2	1	228	272	0.137255	0.166667	0
423250	4	13	2	1.33499E+12	2	1	229	271	0.137255	0.166667	0
423251	4	13	2	1.33499E+12	2	1	229	271	0.137255	0.166667	0
423252	4	13	2	1.33499E+12	2	1	229	270	0.137255	0.166667	0
423253	4	13	2	1.33499E+12	2	1	229	270	0.137255	0.166667	0
423254	4	13	2	1.33499E+12	2	1	229	269	0.137255	0.166667	0

Source: https://www.mariofrank.net/touchalytics/
Configuration: Download the Csv file and upload it onto Colab File System

2.3 Data Loading and Preprocessing

2.3.1 Loading Mobile Data and assigning Indices to features

```
print("--- STEP 1: LOADING & PAIRING DATA ---")
try:
    df_mob = pd.read_csv('/content/data.csv', header=None, engine='python')
except FileNotFoundError:
    print("ERROR: '/content/data.csv' not found. Please upload your mobile data file.")
    exit()

#Given Indices: [1:user, 3:time, 4:action, 6:x, 7:y, 8:pres]
USER, TIME, ACTION, X, Y, PRES = 1, 3, 4, 6, 7, 8

def get_mobile_features(df):
    data = df.values
    feats, labs = [], []
    stroke = []
    for row in data:
        try:
            if row[ACTION] == 0: stroke = [row]
            elif row[ACTION] == 2 and stroke: stroke.append(row)
            elif row[ACTION] == 1 and len(stroke)>1:
                stroke.append(row)
                s = np.array(stroke)
                if s[0,USER] == s[-1,USER]:
                    dur = s[-1,TIME]-s[0,TIME]
                    dist = np.sum(np.sqrt(np.diff(s[:,X].astype(float))**2 + np.diff(s[:,Y].astype(float))**2))
                    pres = np.mean(s[:,PRES].astype(float))
                    if dur>50 and dist>10:
                        feats.append([dur, dist, pres, dist/dur])
                        labs.append(s[0,USER])
                stroke=[]
        except: continue
    return np.array(feats), np.array(labs)

X_m_all, y_m_all = get_mobile_features(df_mob)
print(f"Mobile Loaded: {len(X_m_all)} strokes from {len(np.unique(y_m_all))} users.")
```

2.3.2 Loading Mobile Data and Keeping the first 41 users to match Mobile Data

```
desktop = "/content/DSL-StrongPasswordData (1).csv"
try:
    df_desk = pd.read_csv(desktop)
except:
    print("Error loading CMU data. Check Path.")
    exit()

# Keeping first 41 users to match mobile
users_cmu = df_desk['subject'].unique()[:41]
df_desk = df_desk[df_desk['subject'].isin(users_cmu)]
X_d_all = df_desk.iloc[:, 3:].values
y_d_all = df_desk['subject'].values
print(f"Desktop Loaded: {len(X_d_all)} samples from {len(np.unique(y_d_all))} users.")
```

2.3.3 Pairing users from each dataset and Normalising the Data

```
# 3. PAIRING to stimulate one user using both devices
print("Pairing Users")
final_Xd, final_Xm, final_y = [], [], []

unique_mob = np.unique(y_m_all)
unique_desk = np.unique(y_d_all)
min_users = min(len(unique_mob), len(unique_desk))

for i in range(min_users):
    dm = X_m_all[y_m_all == unique_mob[i]]
    dd = X_d_all[y_d_all == unique_desk[i]]
    n = min(len(dm), len(dd))
    if n > 20:
        final_Xm.append(dm[:n])
        final_Xd.append(dd[:n])
        final_y.extend([unique_desk[i]] * n)

X_D = np.vstack(final_Xd)
X_M = np.vstack(final_Xm)
Y = np.array(final_y)

# Normalize
X_D = StandardScaler().fit_transform(X_D)
X_M = MinMaxScaler().fit_transform(X_M)

print(f"FINAL FUSION DATASET: {len(Y)} samples.")
```

3 Machine Learning Implementation

3.1 Training the Random Forest Classifier

```
# --- STEP 2: TRAINING & FUSION ---
print("\n--- STEP 2: RUNNING FUSION ---")

target = unique_desk[0]
y_bin = np.where(Y == target, 1, 0) # 1 = Target, 0 = Attacker

# Split
Xd_train, Xd_test, Xm_train, Xm_test, y_train, y_test = train_test_split(
    X_D, X_M, y_bin, test_size=0.2, stratify=y_bin, random_state=42
)

# Train RFs
rf_d = RandomForestClassifier(n_estimators=100).fit(Xd_train, y_train)
rf_m = RandomForestClassifier(n_estimators=100).fit(Xm_train, y_train)
```

3.2 Applying Fusion to the Individual Modalities

```
# Predict Probabilities
p_d = rf_d.predict_proba(Xd_test)[:, 1]
p_m = rf_m.predict_proba(Xm_test)[:, 1]
p_fused = (0.5 * p_d) + (0.5 * p_m)#applying the simple weighted sum rule

y_pred_d = rf_d.predict(Xd_test)
y_pred_m = rf_m.predict(Xm_test)
y_pred_f = np.where(p_fused > 0.5, 1, 0)

# Calculate EER
def get_eer(y_true, y_score):
    fpr, tpr, _ = roc_curve(y_true, y_score)
    eer = brentq(lambda x : 1. - x - interp1d(fpr, tpr)(x), 0., 1.)
    return eer, fpr, tpr

eer_d, fpr_d, tpr_d = get_eer(y_test, p_d)
eer_m, fpr_m, tpr_m = get_eer(y_test, p_m)
eer_f, fpr_f, tpr_f = get_eer(y_test, p_fused)

print(f"\nResults for Target {target}:")
print(f"Desktop EER: {eer_d:.4f}")
print(f"Mobile EER:  {eer_m:.4f}")
print(f"FUSED EER:   {eer_f:.4f} << IMPROVEMENT")
```

4 Visualisation

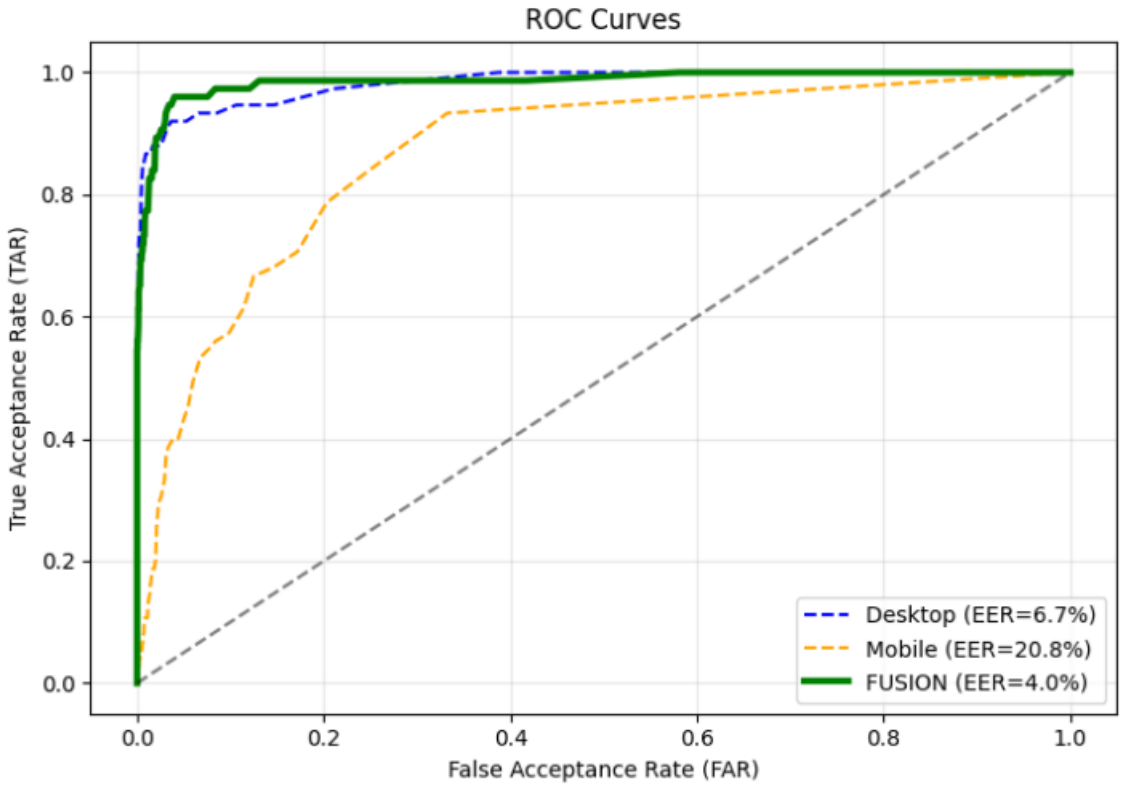
4.1 Plotting ROC and Confusion Matrixes for Each Modality

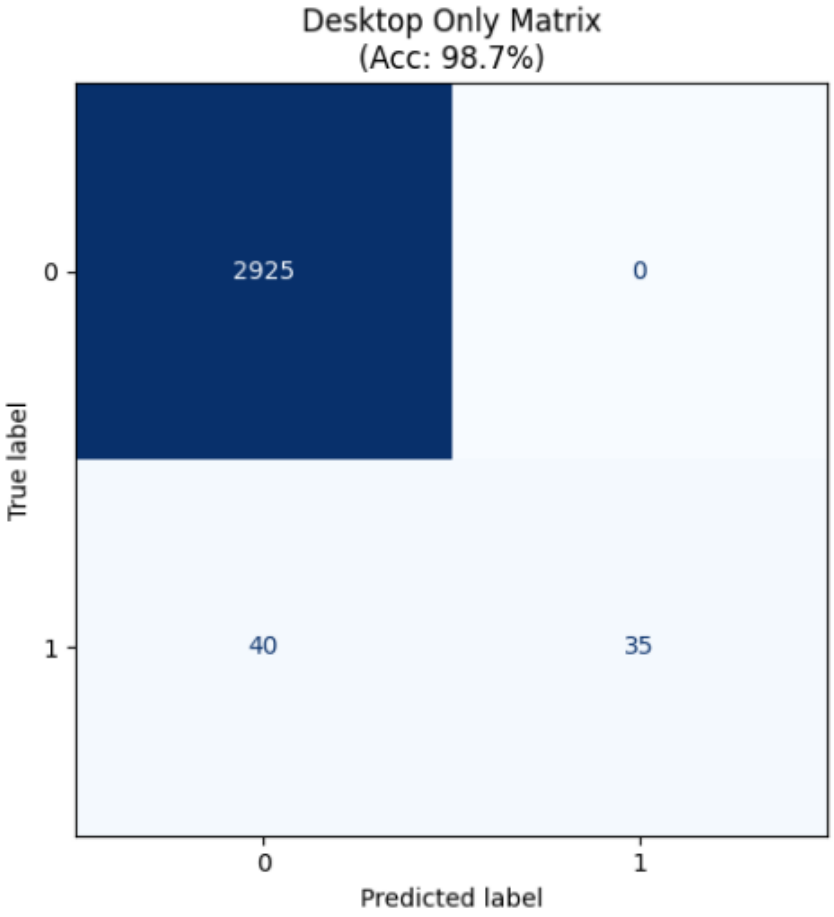
```
fig, axes = plt.subplots(2, 2, figsize=(14, 12))
plt.suptitle(f'Multimodal Authentication Results (Target: {target})', fontsize=16)


axes[0, 0].plot(fpr_d, tpr_d, linestyle='--', color='blue', label=f'Desktop (EER={eer_d:.1%})')
axes[0, 0].plot(fpr_m, tpr_m, linestyle='--', color='orange', label=f'Mobile (EER={eer_m:.1%})')
axes[0, 0].plot(fpr_f, tpr_f, color='green', linewidth=3, label=f'FUSION (EER={eer_f:.1%})')
axes[0, 0].plot([0, 1], [0, 1], 'k--', alpha=0.5)
axes[0, 0].set_title('ROC Curves')
axes[0, 0].set_xlabel('False Acceptance Rate (FAR)')
axes[0, 0].set_ylabel('True Acceptance Rate (TAR)')
axes[0, 0].legend()
axes[0, 0].grid(True, alpha=0.3)

# Plot 2: Desktop Confusion Matrix (Top Right)
ConfusionMatrixDisplay.from_predictions(y_test, y_pred_d, ax=axes[0, 1], cmap='Blues', colorbar=False)
axes[0, 1].set_title(f'Desktop Only Matrix\n(Acc: {np.mean(y_test==y_pred_d):.1%})')

# Plot 3: Mobile Confusion Matrix (Bottom Left)
ConfusionMatrixDisplay.from_predictions(y_test, y_pred_m, ax=axes[1, 0], cmap='Oranges', colorbar=False)
axes[1, 0].set_title(f'Mobile Only Matrix\n(Acc: {np.mean(y_test==y_pred_m):.1%})')

# Plot 4: Fusion Confusion Matrix (Bottom Right)
ConfusionMatrixDisplay.from_predictions(y_test, y_pred_f, ax=axes[1, 1], cmap='Greens', colorbar=False)
axes[1, 1].set_title(f'FUSION Matrix\n(Acc: {np.mean(y_test==y_pred_f):.1%})')

plt.tight_layout(rect=[0, 0.03, 1, 0.95])
plt.savefig("Thesis_Final_Dashboard.png")
print("Dashboard saved as 'Thesis_Final_Dashboard.png'")
plt.show()
```

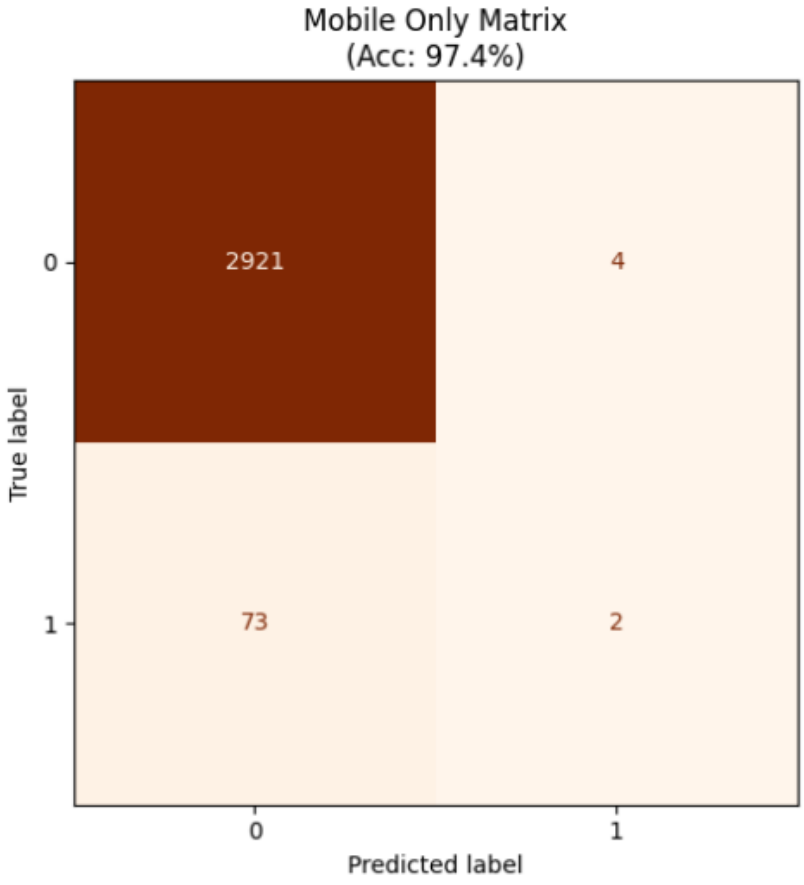
4.2 Outputs Achieved

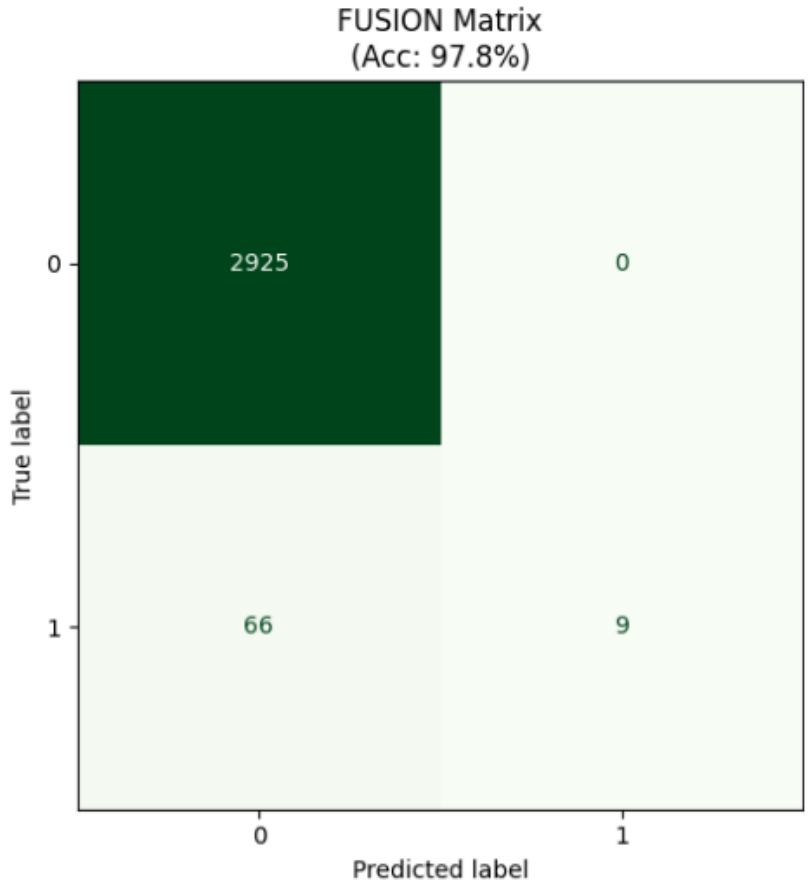
```
--- STEP 1: LOADING & PAIRING DATA ---
Mobile Loaded: 20682 strokes from 41 users.
Desktop Loaded: 16400 samples from 41 users.
Pairing Users...
FINAL FUSION DATASET: 14997 samples.
```

```
--- STEP 2: RUNNING FUSION ---

Results for Target s002:
Desktop EER: 0.0667
Mobile EER:  0.2078
FUSED EER:   0.0400 << IMPROVEMENT
```




Desktop Only Matrix
(Acc: 98.7%)
2925
0
40
35
0
1
True label
0
1
Predicted label


Mobile Only Matrix
(Acc: 97.4%)
2921
4
73
2
0
1
True label
0
1
Predicted label


FUSION Matrix
(Acc: 97.8%)
2925
0
66
9
0
1
True label
0
1
Predicted label