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Optimizing Antiretroviral Therapy (ART) Adherence Through Predictive Analytics Using Machine Learning Techniques

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Abstract

HIV and AIDS remain prominent global health concerns and antiretroviral medication (ART) plays a crucial role in treating infected individuals, preventing disease progression, and improving overall health outcomes. However, missed appointments in ART programs pose significant challenges by causing treatment interruptions, unsuppressed viral load, and increased HIV transmission rates. This research employs the CRISP-DM methodology and aims to develop a predictive model that effectively reduces missed appointments among people living with HIV. A comprehensive analysis of patient data, including demographics, clinical information, and appointment history, was conducted to determine the key factors influencing missed appointments. The prediction model was developed using decision trees, random forests, and support vector machines. The study found that decision trees produced the best results, having lower square errors and greater R squared. The findings contribute to the advancement of predictive analytics in healthcare, particularly in the context of chronic conditions such as HIV/AIDS.

Keywords

HIV/AIDS, Antiretroviral medication (ART), Missed appointments, Adherence, Machine learning.

1. Introduction

HIV and AIDS remain a major issue in Zimbabwe, where an estimated 1.3 million people, or 11.58% of the population, live with the virus as of 2021 (UNICEF 2023). Antiretroviral Therapy (ART) is a critical treatment for individuals living with HIV/AIDS, as it helps manage infection, prevent disease progression, and improve overall health

outcomes. Lowane and Lebesse (2020) described missed appointments as failing to attend or not showing up for clinic appointments for longer than five or seven days following the date of their next scheduled visit. A higher risk of adverse immunological responses and poor drug adherence is associated with skipping clinical sessions while on antiretroviral therapy (ART) (Lowane and Lebesse 2022). The rapid expansion of antiretroviral therapy raises concerns about the development and spread of drug-resistant HIV strains due to unsuccessful treatment (Haile et al. 2016). Missed appointments not only have a substantial effect on patient treatment but also disrupt healthcare system efficiency, heighten the risk of immunological and clinical failure, and potentially result in interruptions to HIV therapy (Lowane and Lebesse 2022). To improve treatment outcomes and prognoses, individuals with HIV/AIDS must regularly attend clinics for drug refills, routine laboratory testing, and clinician evaluations (Abdulrahman et al. 2019).

UNAIDS postulated that suppressed viral load is equal to untransmissible HIV infection (Frescura et al. 2022). Prah et al. (2018) over the years, the number of people receiving treatment has gradually increased, reaching 19.5 million in 2016 and this has decreased the number of new cases of HIV infection, comorbid conditions, & AIDS-related fatalities, particularly in low- and middle-income nations. Clinical research shows that skipping appointments is a strong predictor of poor health outcomes, particularly for patients with multiple chronic conditions and high deprivation-inpatient groups (Ellis et al. 2022). Patients with poor adherence defined as missing more than three sessions each month had an 8.6 times higher risk of treatment failure than their counterparts (good adherence), (Ellis et al. 2022). There is a geographical gap in our attempts to meet the 2030 target of ending the HIV epidemic, as evidenced by the paucity of research conducted in Zimbabwe. A patient's risk of having interrupted treatment (IIT) increases with the number of missed appointments for antiretroviral therapy (ART) clients. Missed appointments lead to defaulting or interruption in treatment (IIT) which has potential individual & public health effects, increased HIV transmission, and risk of death (Mtisi et al. 2023). As antiretroviral therapy (ART) is lifetime and quitting it quickly causes a viral rebound, patients are at a higher risk of contracting a sickness that defines AIDS and of spreading the virus to others (Esra et al. 2023). Globally, efforts are being made to achieve Vision 2030 of ending epidemics such as new HIV infections (Frescura et al. 2022). Missing these appointments can lead to delayed disease assessment, inadequate treatment adjustments, and potential complications due to the lack of timely monitoring and intervention (Ramachandran et al. 2020).

This paper is structured as follows: Section 1 provides the study's background, Section 2 presents a literature review, Section 3 outlines the methods used, Section 4 describes the data collection process and the final section presents the results and discussion.

1.1 Objectives

The objectives of this research are to:

- Determine factors contributing to missed appointments among patients undergoing antiretroviral therapy (ART)
- Develop machine learning techniques that mitigate missed appointment predictors.

2. Literature Review

A comprehensive search of published articles from reputable information databases was conducted in PubMed, Medline, Google Scholar, IEEE, Springer, and the Cochrane Database of Systematic Reviews.

Since 2015, the World Health Organization (WHO) has recommended that all people living with HIV receive antiretroviral therapy (ART), irrespective of their clinical stage or CD4 count. The "Treat All" policy's adoption and the extension of ART services provide advantages for the individual as well as the community. These advantages include a decrease in HIV transmission, an increase in the life expectancy of HIV-positive individuals, and a decrease in death rates (Burke et al. 2024). Prah et al. (2018) described adherence as a patient's compliance with taking prescribed medications as instructed by a doctor; this includes adhering to schedules, dosage instructions, and dietary recommendations. Antiretroviral therapy (ART) non-adherence is the main factor contributing to the development of medicine resistance and treatment failure. To guarantee the best possible virologic results, doctors and patients must work together to ensure ongoing optimal adherence to antiretroviral medication.

Key Factors contributing to Missing Appointments

Denney et al. (2019) did a study on machine learning predictions of No-Show appointments in primary care settings and discovered three key variables: the patient's age, the total number of missed appointments in the past, and the amount of time that had passed between the booking date and the appointment date. Lowane and Lebesse (2022) Instead of attending ART appointments, participants offered a range of justifications, such as inadequate family support, financial difficulties, failure to disclose HIV status at work, and not including patients in appointment scheduling. They emphasized that a variety of factors, including shifting priorities, important life events, and forgetfulness, could predict a person's likelihood of missing an appointment. The researchers hypothesized that older patients have less appetite for missing their appointments due to the inherent risk of aging and failing health compared to younger patients, who are associated with a high probability of missing appointments. In addition to past missed appointments being a significant factor, they also found that age played a significant role (Sangeda et al. 2018).

Abdulrahman et al. (2019) highlighted that most studies hypothesized that patient and provider-related variables, healthcare delivery systems, sociodemographic variables, and socioeconomic variables would all have a substantial impact on non-adherent clinic attendance; however, these results varied widely throughout European, African, and Asian subcontinents. Prah et al. (2018) Respondents who missed their appointment at the ART clinic gave many excuses, including being away from home, forgetfulness, being distracted by other issues, and not having enough money for transportation for the monthly refill. Bukenya et al. (2019) discovered that the following factors contributed to low long-term ART adherence: stigma, travel for business or social activities, insufficient or nonexistent continuing education on ART adherence, alcohol usage, and use of other "HIV cure" medications. Additional factors were the adverse effects of antiretroviral therapy, treatment exhaustion, faith in God or long-term ART as a means of "curing" HIV, and food security.

Related works

Bukenya et al. (2019) investigated the reasons behind non-adherence in people with inadequate viral suppression using a qualitative cross-sectional study carried out in Uganda. The study highlighted the significance of continuous ART adherence education for optimal treatment outcomes, utilizing in-depth interviews and thematic analysis, but was limited by the lack of a quantitative approach.

Ramachandran et al. (2020) evaluated five machine learning models' effectiveness for predicting care retention and access to the techniques currently employed by HIV doctors. The results showed that the Random Forest model performed best in predicting patients' retention in care as well as their access to it. However, the study only included patients who were 18 years and above, which may have limited the generalizability of the results to the entire population. Salazar et al. (2022) concurred that in the healthcare industry, a patient's no-show rate can be predicted using the Random Forest Model.

Using secondary electronic medical record data and machine learning techniques, researchers in Tanzania conducted a two-year proof-of-concept study to predict the future chance of disengagement from HIV care in individuals who had recently started antiretroviral therapy (Fahey et al., 2022). They developed ensemble decision tree-based supervised machine learning models to predict the probability of obtaining less HIV medication. This research made sense to use the aggregated decision tree learning technique (common in EMR data) because of the smaller sample size and the possibility that missing data could significantly affect prediction accuracy.

Several models were examined, evaluating the predictive power of the logistic regression, random forest, and AdaBoost algorithms to investigate demographic, clinical, behavioral, and laboratory data as predictor variables for attending the next scheduled visit and viral load results at the next test (Maskew et al., 2022). Extreme Gradient Boosting and Boosting Tree were two examples of boosting classification algorithms used to build predictive models for future IITs (Ogbechie et al., 2023).

Research Gap from Existing Literature

The following gaps were identified from the existing reviewed literature for HIV/ AIDS treatment management: Retention on antiretroviral therapy (ART) is still difficult worldwide. In South Africa, for instance, 11–28% of patients become lost to follow-up (LTFU) within the first two years of starting treatment, even though it is a lifetime treatment. Patients who stop treatment too soon risk contracting a viral rebound, which puts them at risk of getting the illness that characterizes AIDS and of infecting others (Esra et al., 2023). In their study, the researchers used the CatBoost

algorithm and found that historical visit attendance alone could predict nearly half of the next missed visits, but they did not address strategies to reduce missed appointments. Denney et al (2019) highlighted that people may become forgetful which may be ideal if additional communication reminders for patients with at least one month of booking in advance.

Routinely collected service delivery data can be leveraged to develop high-performing machine learning (ML) models for identifying HIV patients at risk of Interrupted Treatment (IIT) and integrating them into routine health management information systems. Mukura and Ndlovu (2023) highlighted that the prevalence of research conducted in developed countries suggests that artificial intelligence has achieved more significant progress in those regions compared to developing countries, where alternative methods unrelated to machine learning are still being employed. The implementation of ML can enhance intervention targeting through differentiated models of care, leading to improved patient outcomes and increased cost-effectiveness Ogbachie et al. (2023). Nonetheless, it's crucial to remember that there is limited research conducted in this field within Zimbabwe, suggesting a restricted utilization of data-driven ML techniques in healthcare.

3. Methods

The study used the Cross-Industry Standard Process data mining (CRISP-DM), which describes the procedures that must be followed to complete a product or service and establish a framework of reference for data mining activities (Studer et al. 2021). The CRISP-DM methodology is used because, among related process models, it is seen to be the most appropriate for industrial projects and is based on practical experience with industrial data mining (Studer et al. 2021). Business Understanding, Data Understanding, Data Preparation, Modeling, Evaluation, and Deployment are the six phases that make up the process.

During the business-understanding phase, it was noted that ensuring ongoing adherence to therapy necessitates the active, secure, and confidential tracking of patients (PEPFAR 2023). To maintain patient confidentiality while contacting individuals experiencing interruptions in therapy, healthcare professionals should follow best practices. In the data-understanding phase, the researchers gained insight into the data properties, explored its features, and verified its quality. Electronic health records were used to collect non-patient identifiable data on various ART treatment indicators, including demographics, medication duration, activity status, and history of treatment default. The ART complete metabase was downloaded in CSV format and data coding and preparation involved selecting indicators (feature selection) that reflect ART adherence, as well as cleaning and removing missing data. A confusion matrix, accuracy, recall, and precision were used to assess the performance of three models: Support Vector Machine, Random Forest, and Decision Tree. The results were thoroughly reviewed to assess the models' suitability for the dataset and development planning.

4. Data Collection

The data for the study was obtained from a local health center and covered ART visits between October 2022 and October 2023. A measure called TX_Curr was calculated, representing the number of active ART clients in the cohort during the specified period. The collected data was securely stored on an encrypted laptop, and any patient-identifiable information was removed to uphold confidentiality. Feature engineering techniques were applied to identify and include the most influential features that contribute to the desired outcome. The data was coded to numerical and variable definitions are presented in Table 1:

Table 1. Variables description

Parameter	Description
Gender	Patient's gender, Female =1, Male =0
Age	Patient's age (years)
Marital status	Patient's marital status, never married= 0, married =1, cohabiting =2, separated =3
POP Type	population, sex worker =1, General population =2, High risk men= 3, Men having sex with men=0, Transgender =4
Months in ART	Number of months in ART program

ever defaulted	has the client defaulted treatment for more than 28 days
NUMBER OF VISITS	Number of visits attended in the year under review (oct22 -oct23)
Activity	Patient's activity status, Interruption in treatment =1, Active 2, deceased =0, Transferred out=4
MMD	Duration of medication in months resupplied
DAYS TO NEXT REFILL	Days left or passed to the next scheduled appointment
a_viral_load_result	Viral load result
Active Jan24	Clients who were in the OCT 2023 cohort are still active in the January 2024 cohort.
Missed Appointment	Those that have already missed their scheduled appointment as of 31 October 2023

5. Results and Discussion

Machine learning algorithms were employed to analyze the data using Python software. Before the analysis, various packages, including pandas, NumPy, and Scikit-learn, were installed to facilitate data manipulation and modeling. Exploratory data analysis was performed using functions such as describe (), info (), and shape () to gain insights into the dataset's characteristics and structure. These steps provided a foundation for further analysis and modeling of the data.

5.1 Results

The correlation heatmap (Figure 1) offers important information on the variables impacting HIV-positive people's missing antiretroviral therapy (ART) appointments. Notably, the duration of medication shows a strong positive correlation with the number of months after initiation and days until the next refill. This correlation implies that patients who have been taking medication for a long time are more likely to keep their appointments and make sure their prescriptions are filled on time. Similarly, the days to the next refill exhibit a strong positive correlation with both the duration of medication and the number of months after initiation, indicating that patients with longer treatment histories tend to schedule their refill appointments promptly.

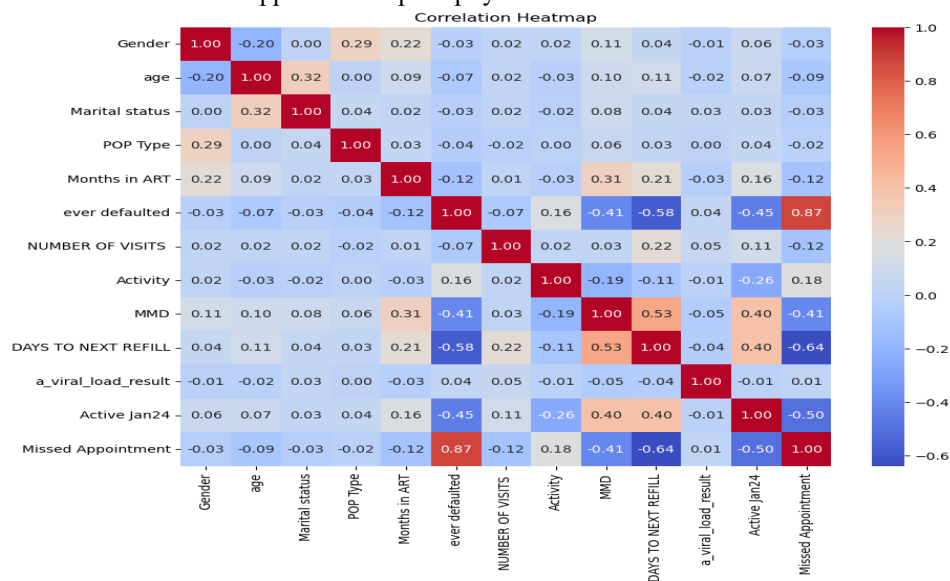
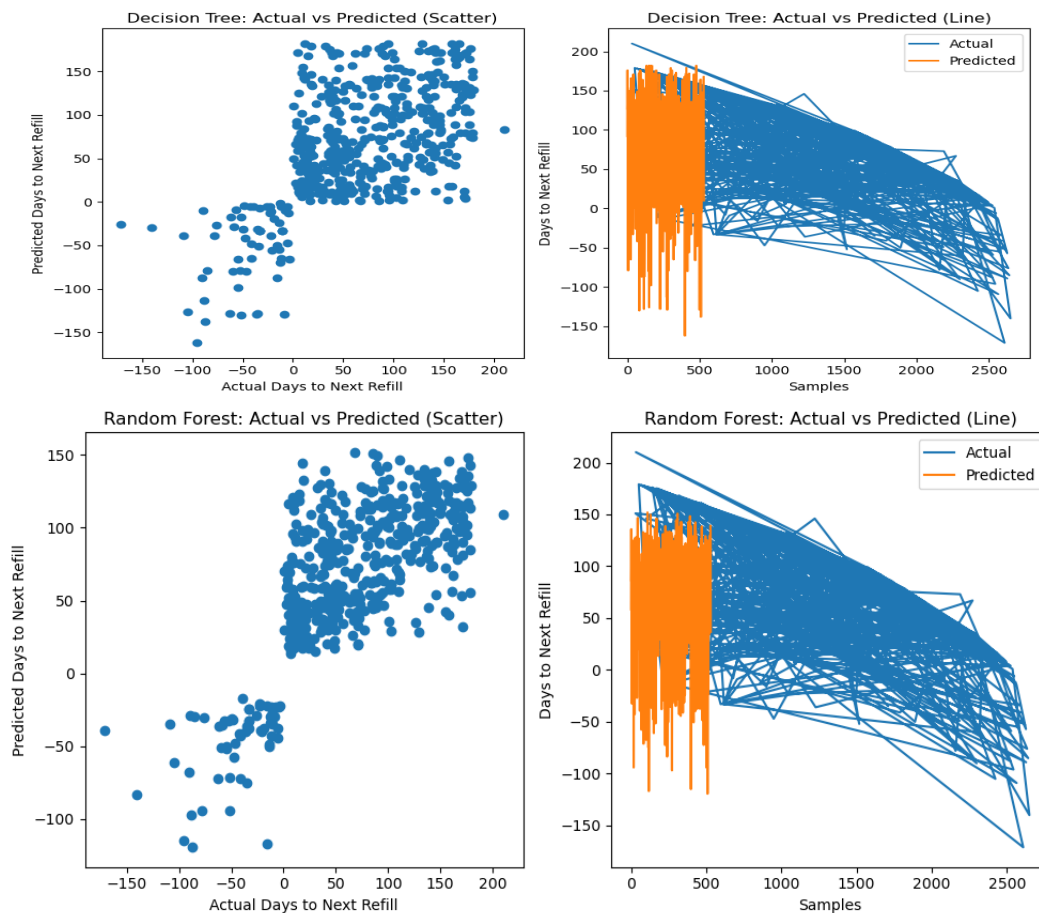


Figure 1. Correlation Heatmap

Another significant finding is the moderate negative correlation between activity status (e.g., interruption in treatment) and appointment adherence. This implies that interruptions in treatment are associated with a higher likelihood of missed appointments, emphasizing the importance of consistent engagement in ART for maintaining appointment schedules. Additionally, while gender and age show minor correlations with appointment-related factors, marital status does not appear to have a significant influence on missed appointments in this context. This suggests that factors such as age, gender and marital status may have varying degrees of impact on appointment adherence, with other variables like treatment duration and activity status playing roles that are more substantial.

These findings align with existing literature, such as studies by Abdulrahman et al. (2019) and Fahey et al. (2022), which emphasize the importance of factors like treatment duration and activity status in predicting missed appointments in HIV care. Understanding these correlations is crucial for developing effective strategies to minimize missed appointments and improve engagement in ART. The Decision Tree and Random Forest model's ability to capture complex relationships among these factors makes it a suitable choice for predicting and addressing missed appointments in HIV care settings, ultimately contributing to better patient outcomes and treatment adherence.



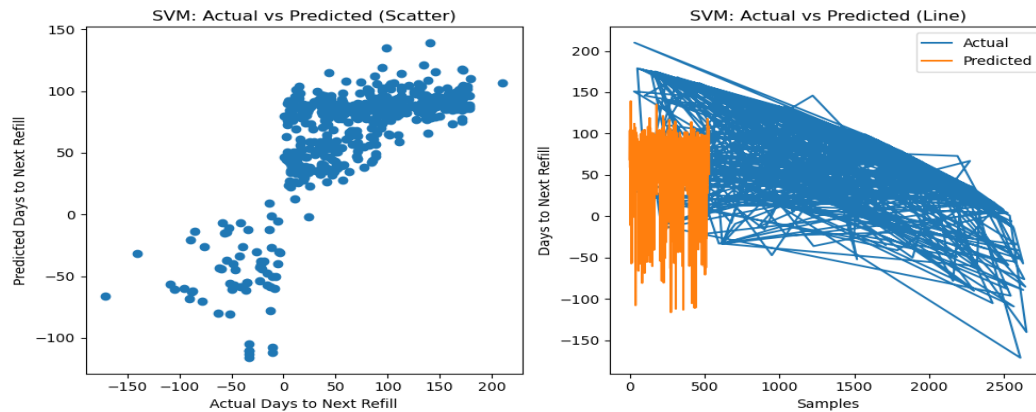


Figure 2. Prediction models

The results from the predictive models for minimizing missed appointments in Antiretroviral Therapy (ART) among individuals living with HIV indicate varying levels of performance across different machine learning techniques as shown in Figure 2 above.

5.3 Proposed Improvements

The study results suggest that health institutions can reduce the number of missed appointments by addressing clients who possess characteristics identified as key factors. Specifically, individuals with a history of treatment default should be continuously educated on the importance of adhering to their treatment. This can be achieved through counseling sessions conducted during their scheduled visits.

5.4 Validation

The Decision Tree model achieved the lowest MSE (0.00376648), highest R-squared (0.982172) and lowest MAE (0.00376648), indicating better accuracy, variance explained and smaller average absolute error, respectively. The Random Forest model had slightly higher MSE (0.00388663) and slightly lower R-squared (0.981604) compared to the Decision Tree model, but still performed well. It also had a higher MAE (0.00696798) compared to the Decision Tree model. The SVM model had the highest MSE (0.00591969), lowest R-squared (0.97198) and highest MAE (0.0437022), indicating relatively lower performance across all metrics as shown in Table 2 below.

Table 2. Model Evaluation

Model	MSE	R ²	MAE
Decision Tree	0.00376648	0.982172	0.00376648
Random Forest	0.00388663	0.981604	0.00696798
SVM	0.00591969	0.97198	0.0437022

6. Conclusion

In conclusion, the objective of this study was to identify key factors contributing to missed appointments for Antiretroviral Therapy (ART) among individuals living with HIV. The correlation heatmap analysis revealed several important findings. The duration of medication showed a strong positive correlation with the number of months after initiation and days until the next refill, indicating that patients with longer treatment history are more likely to adhere to their appointment schedules and timely medication refills. Activity status, such as treatment interruptions, exhibited a moderate negative correlation with appointment adherence, emphasizing the need for consistent engagement in ART. Factors like gender, age and marital status had minor correlations with appointment-related factors. Overall,

understanding these factors is crucial for developing effective strategies to reduce missed appointments and improve treatment adherence in HIV care settings.

The study findings align with previous research, including Abdulrahman et al. (2019) and Fahey et al. (2022), indicating that machine learning techniques, particularly Decision Tree and Random Forest models, are effective in predicting missed appointments and improving healthcare outcomes in HIV care. These models' ability to capture complex relationships, handle noise effectively and provide accurate predictions makes it the most suitable choice for minimizing missed appointments compared to SVM models. Therefore, implementing the Decision Tree and Random Forest model in practice is recommended to optimize appointment scheduling and reduce missed appointments among individuals living with HIV. The researcher recommends implementing electronic medical records and utilizing real-time data analysis with machine learning techniques to obtain district or geography-specific results. These evidence-based data insights can inform implementation and programming decisions.

7. Future work

Integration of Real-Time Data: Explore the integration of real-time data streams, such as wearable devices or mobile health applications, to provide continuous monitoring of patient behavior and adherence patterns. This could enable timely intervention and personalized support to prevent missed appointments.

Personalized Intervention Strategies: Investigate the development of personalized intervention strategies tailored to individual patient characteristics and adherence patterns. This could involve adaptive approaches that dynamically adjust based on patient responses and feedback.

Longitudinal Analysis: Conduct longitudinal analysis to track changes in predictors of missed appointments over time and assess the effectiveness of interventions in mitigating these factors. Long-term monitoring could provide insights into patient adherence trajectories and inform proactive intervention strategies.

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Biographies

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Sibusisiwe Dube is a Professor, senior lecturer and projects coordinator in the Department of Informatics and Analytics at the National University of Science and Technology. She holds a Ph.D. in Information Systems from the University of Cape Town, South Africa, a Master of Science degree in Computer Science from the National University of Science and Technology in Bulawayo, Zimbabwe and a Bachelor of Science Honors degree in Information Systems from Midlands State University, Zimbabwe. Her research interests encompass Information and Communication Technology for Development (ICT4D), the Digital divide, ICT in education and the paradox of the second-order digital divide in highly literate country's higher education institutions. Sibusisiwe has received research awards, including the NUST RIO grants in 2014 and 2016, as well as conference travel funding from UCT in 2016.

Dr. Fungai Jacqueline Kiwa holds a Doctor of Philosophy Degree in Cultural Heritage and Information Technology from Chinhoyi University of Technology, complemented by a Post Graduate Diploma in Higher Education. Additionally, she holds a Master of Science degree in Information Systems, a Bachelor of Technology (Honors) degree in Computing and Information Technology and an Advanced Diploma in Computing and Information Technology. With a wealth of academic achievements, Dr. Kiwa has authored 17 publications, encompassing articles, conferences, thesis and dissertations. Currently, she is a candidate for a Master of Mechatronics and AI at the University of

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