Prostate Cancer Monitoring using MRI Monomodal Feature-Based Registration

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Abstract. Image registration approaches based on standard information criteria were widely employed, showing promising results in the registration of medical monomodal images. Feature-based registering is an effective clinical application technique since computational costs can be reduced significantly. The following four steps are generally used for most registration methods: detection of features, extraction of features, matching features and transformation determination. The accuracy of the registration procedure is dependent on matching a feature and detecting control points (CP). Thus, this paper supports this feature for monomodal registration of magnetic resonance imaging (MRI). MRI is gold-standard imaging to detect prostate cancer progression as it provides better information for soft tissue visualization. In this study, registration of MRI images taken from different time frames is developed to ease the physician in integrating the information about the evolution of the tumour. The accuracy of the registration process depends on matching features and CP detection by calculating the iterative closest point (ICP). The prostate volumes are calculated, and the result shows minimal errors. This registration method has been applied in coronal, sagittal and axial views from five patient datasets. The accuracy of automatic registration results is 0.1mm (axial), 1.1mm (coronal) and 0.2mm (sagittal). These accuracies are comparable to gold-standard manual registration by the experts. There was no significant difference between the automatically and manually registered MRI monomodal. Thus, the proposed method enables the physician to diagnose prostate cancer as it can provide important information about the disease progression and decide the necessary therapies regarding the patient's condition.

Keywords: Magnetic resonance imaging, Monomodal image registration, Prostate cancer, Feature-based registration.

INTRODUCTION

Prostate cancer is a condition when an abnormal tumour and malignant growth of cells occur in the prostate [1]. The common prostate cancer that grows in the tissue of a prostate gland is called adenocarcinoma [2]. It contains 70% of glandular tissue, while another 30% consists of the fibromuscular stroma. Prostate cancer, which continues to be one of the primary causes of cancer-

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related deaths in males in Malaysia and is widespread globally, has more than one million new patients each year [3]. In Tobias Penzkofer's article, it has been stated that in the European Randomized prostate cancer screening survey in 2019, over 1400 people had to be screened, in which 48 had to seek treatment to protect one man from mortality [4].

The important part of the planning of image-guided radiotherapy of prostate cancer is imaging [5]. Prostate cancer is usually diagnosed rooted in Digital Rectal Examinations (DRE) and Prostate Specific Antigen (PSA), as well as ultrasound-guided biopsy [6]. Magnetic resonance imaging (MRI) is a useful imaging method since it has become extensively used for prostate cancer staging through a combination of various MRI-based techniques, for instance, T1-weighted (T1W), T2-weighted (T2W), diffusion-weighted imaging (DWI) and dynamic contrast-enhanced (DCE) imaging [7].

Nowadays, the medical image registration method has become one of vital interest and is widely employed in medical research and health care [8]. Presently, MRI is one of the essential imaging that has been used to detect prostate cancer since it has superior detailing of the soft tissue [9]. It presents a specific imaging modality to define the precision of prostate cancer from another pelvic organ. It may also depict not only the prostate itself but its substructure, including the peripheral zone. Besides, MRI helps diagnose prostate cancer and plan treatment. While MRI provides valuable information, this modality also has certain disadvantages, which may affect the output and, afterwards, the conclusion and decision that the experts must make [10]. Hence, this modality still needs to be improved to gain more knowledge or details and access to the body organs.

In medical imaging, monomodal image registration is a useful approach. However, it is a significant difficulty in practically all medical image processing and clinical applications, for instance, image-guided surgery, radiotherapy, medical treatment, and other applications in diagnosis and treatment [11]. When comparing two images, the similarity measure is used to determine the quality of the registration between the homologous structures. Thus, in recent years, several researchers predicted the necessity to build treatment tools to support the expert in diagnosis preference [12]. In general, it is a clinically aided system committed to doing the assessment. For example, we used this method in this study as it is currently helpful to identify tumours with MRI.

By this monomodal registration, the MRI can enhance the quality of images as well as detect the rate of progression, growth, and evolution of disease by registering two images from different time acquisitions [13]. Prostate shape changes appear between MRI images caused by different times and different positions of patients. Each of the MRI images will provide different stages, shapes, variability, sizes, and locality of the prostate tumour. Monomodal registration tasks assist in an application that copes with growth control, comparing rest-stress, subtraction imaging, intervention validation and many other applications. Using this registration, the physicians can integrate and detect the rate progression of prostate cancer, as it is essential for the treatment planning and diagnosing of the disease.

The purpose of this research is to produce a spatial registration modal for diagnosing and recognizing prostate cancer from MRI images. The physician can facilitate the monomodal registration of MRI with valuable data on the progression of the prostate disease as well as for radiotherapy planning and the procedure of radiation dose planning treatment. This study shows the spatial registration of MRI images for three planar views, consisting of a coronal, sagittal and transverse plane with different times acquisition. It is also validated quantitatively with the accuracy of visualization and the detection of prostate cancer by the monomodal registration model.

MATERIALS AND METHOD

A. MRI Prostate Cancer Acquisition

All data were collected retrospectively in accordance with established clinical acquisition protocols after receiving prior approval from the ethics committee of Universiti Sains Islam Malaysia (USIM). Five patients, all of whom had been diagnosed with prostate cancer, were included in the study and underwent monomodal imaging. The prostate gland is scanned at different times for each individual. According to the Creative Commons Attribution 3.0 Unported License, the data used in this registration were obtained anonymously from an internet database [14], in which informed consent from patients was unnecessary because the data were publically available for educational purposes. MRI images were provided in a DICOM format. The properties of the MRI prostate cancer are as follows:

Type of MRI : T2-weighted (T2W) using a turbo spin-echo
Resolution : 0.55mm
Slice thickness: 3.6mm
Matrix size : 320 × 320 pixels

B. Image Registration

The overall workflow of this study is shown in Figure 1. There are three significant steps in this proposed monomodal registration: pre-processing of two MRI images, point feature-based registration, and accuracy testing. One of the MRI images will be assigned as the fixed image with the size of 320 × 320 pixels, and another image will be the floating image or moving image with the same size of pixels as in the first step. The accuracy of the registration determines this metric to get the similarity feature [15]. The two images of MRI from different times are needed to pre-process before the registration by selecting the middle of three planar illustrations, coronal, frontal and sagittal, to receive the most beneficial alignment results. Then, it resizes the images, eliminating noise or modifying the image quality to tweak with a particular purpose.

The initial step in pre-processing is presenting the images into the MATLAB software, followed by resizing the first MRI image of prostate cancer to align with another MRI image. Next, the pre-processing process selects the middle of three planar views from coronal, sagittal, and frontal to get the best alignment results and resize the images, removing noise and altering the image quality to adapt to a particular purpose. Afterwards, the MRI slice is selected for real-time 2D visualization.

Then, these images of MRI are manually segmented and registered via manual registration, which uses a feature and control point-based registration with the iterative closest point (ICP) in translation and rotation. The ICP is used to fasten the looping to reduce the time taken for registration. Control point-based registration enables standard features to be manually selected in an image to correspond to the exact pixel location. This process is done twice to produce precise images for the registration process. For images with distinct features, this method is best suited. In this experiment, the corresponding anatomical features in MRI images are manually defined by experts in anatomy to assess the appearance of the prostate in registered images.

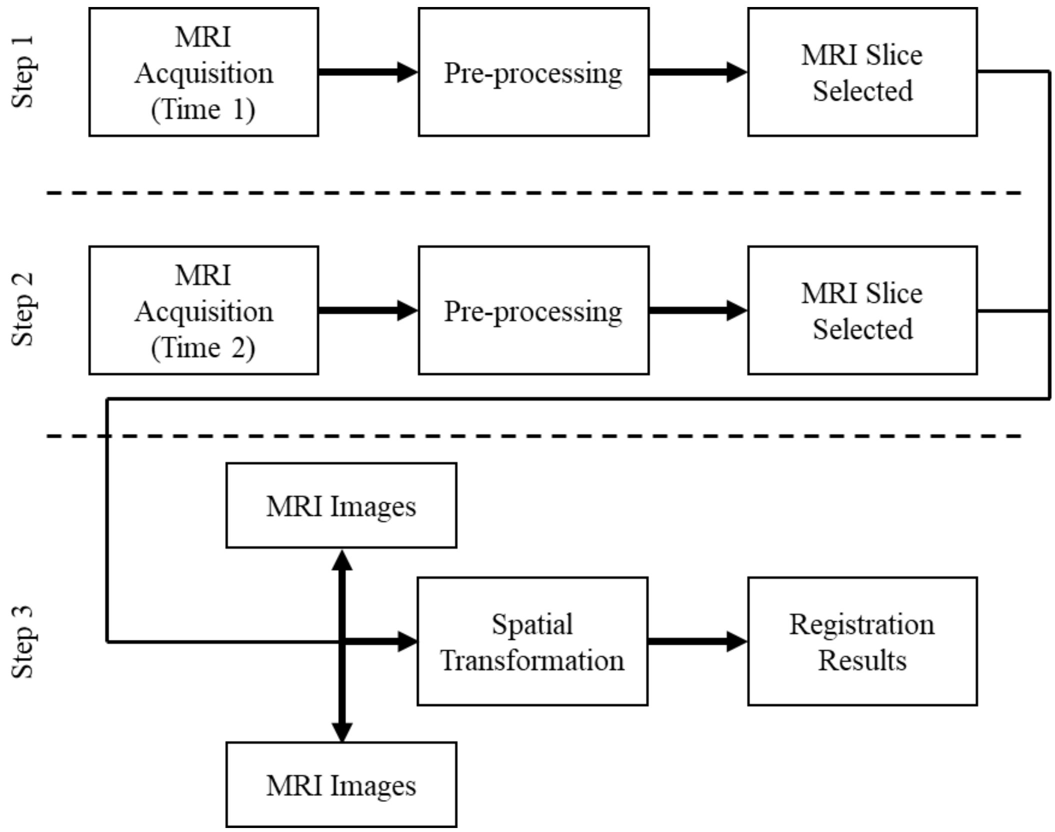


FIGURE 1. Overall image registration workflow.

Next, the spatial transformation is used to fuse the registered images. There is a geometric relationship between each point in the fixed image and the moving image in spatial transformation. A fixed image consists entirely of reference points that clearly define coordinate values. The moving image consists of the observed (warped) data. The general mapping function can be given in two ways: the output coordinate system related to the input or vice versa [16].

Figure 2 describes the overall proposed spatial registration framework of the feature point-based method. It is a two-point registration technique that locates a spatial transformation and plots one point to the other in order to re-create the transformation [17]. Non-rigid and rigid transformations are the two most common types of transformation. In this study, we concentrated on a rigid transformation that enables the process of translation, rotation, and scaling. The point-based registration technique employs a rigid 2D-to-2D direct feature-based registration, with normalized cross-correlation employed to conduct spatial registration between CT and MRI images. Various prostate anatomical locations were chosen during the registration process. To ensure that all of the prostate's most prominent features were represented, a total of 30 points were randomly selected from each MRI scan.

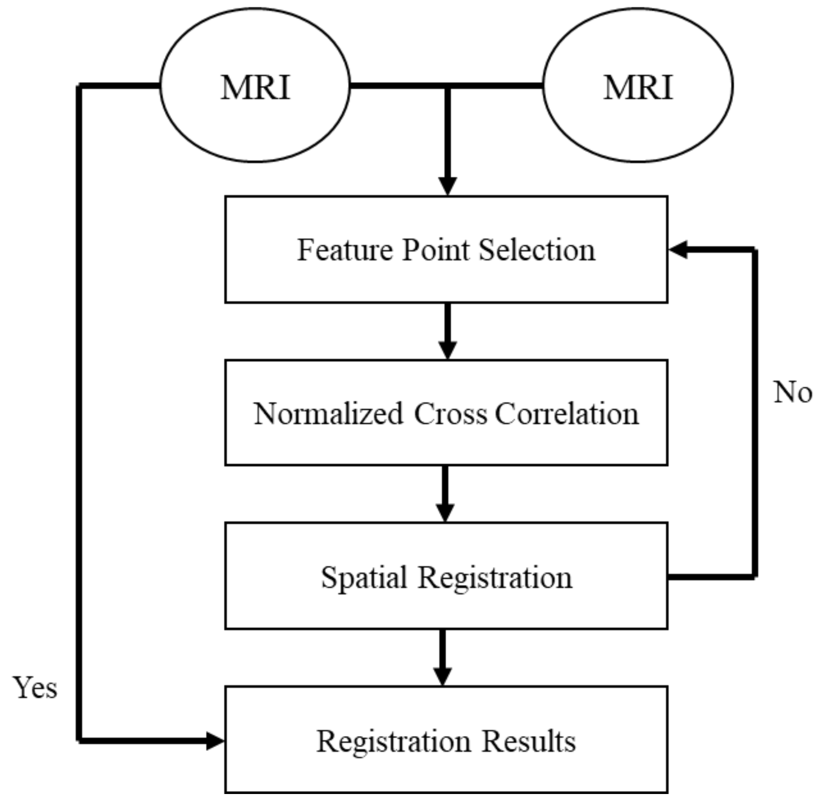


FIGURE 2. Spatial registration pipeline.

The MATLAB software (vR2019b, MathWorks, Natick, USA) is used to form the registration image result on an Intel(R) Xeon (R) CPU E5-26200 @ 2.00 GHz computer software in one output image. The overall proposed registration workflow of this study has been presented in Figure 2. In addition, the accuracy testing of the registration image was calculated quantitatively at the end of the study to validate the monomodal registration model and the evolution of prostate cancer.

C. Validation of Registration Accuracy

The gold-standard manual calculation is being compared with the accuracy of our proposed method. This manual delineation and calculation were done by an expert to calculate the most suitable matching MRI plane through manual manipulation of the transformation parameters in various time acquisitions [18]. Two images are included as primary inputs for the registration process; the first is the fixed image (t1), while the second is the moving image (t2). Registration is considered an optimization problem in determining the spatial mapping that will align moving images with fixed images. Figure 3 shows measurements for length, width, and height from axial, coronal, and sagittal image diameter measurements, respectively. The diameter measurements are chosen based on the maximum length of the volume of the ellipsoid prostate.

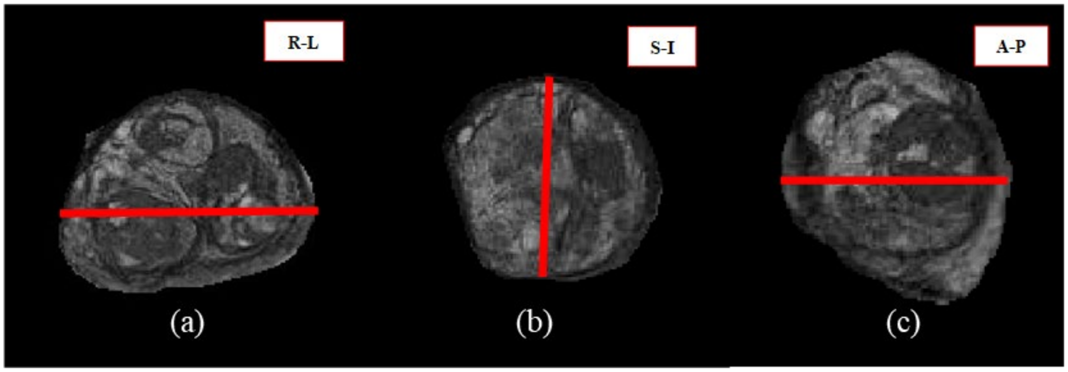


FIGURE 3. Volume measurement of the ellipsoid prostate on triplane (a) axial, (b) coronal, (c) sagittal. T2W MRI images using the formula right-to-left (R-L) diameter, anterior-posterior (A-P) diameter, and superior-inferior (S-I) diameter.

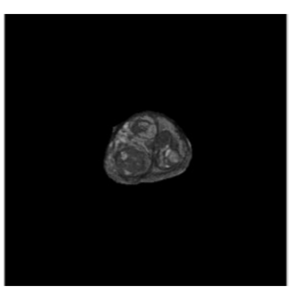
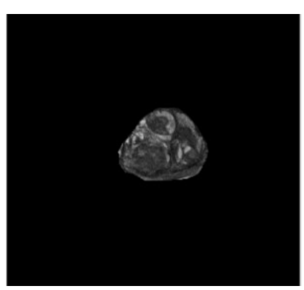
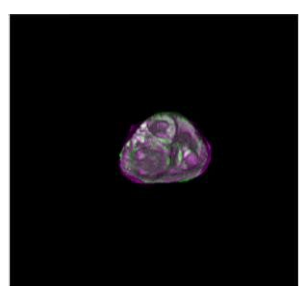
The volume of prostate cancer was calculated by using Equation 1 in this study. It is known as the standard ellipsoid formula for calculating prostate volume. Ellipsoid is the closed surface of which all plane cross-sections are either ellipses or circles. An ellipsoid is symmetrical about three mutually perpendicular axes intersecting at the centre (the middle of 3 planar views, which are axial, coronal and sagittal).

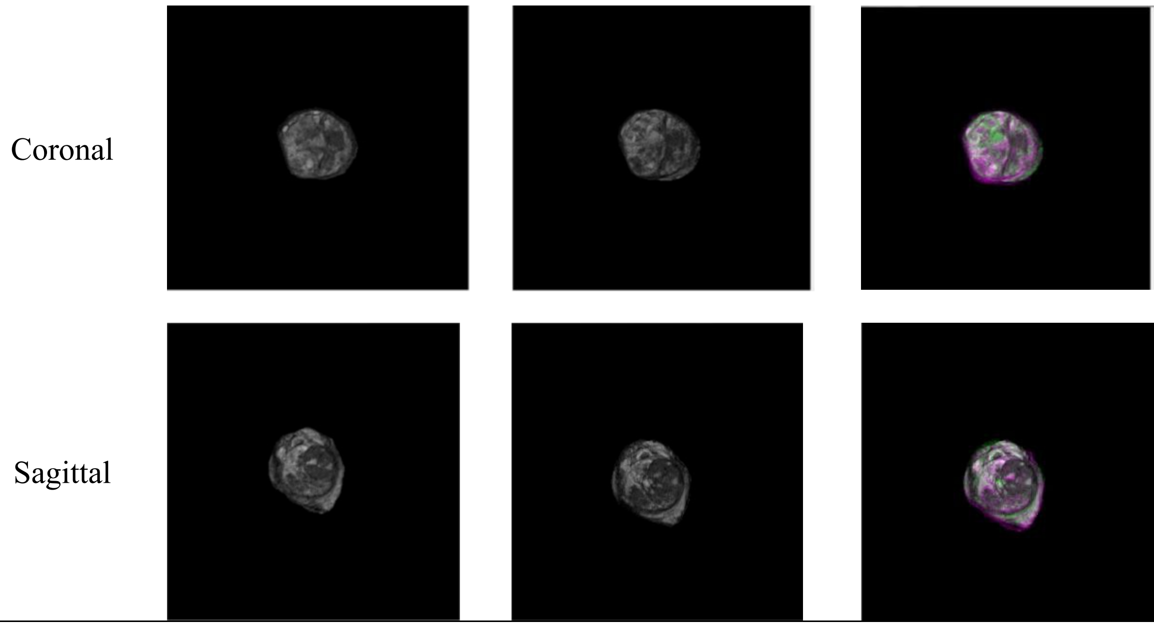
$$\text{Volume} = \text{length (axial)} \times \text{width (sagittal)} \times \text{height (coronal)} \times 0.52 \div \frac{\pi}{6} \qquad (1)$$

RESULT AND DISCUSSION

The registration steps are validated on five patients with prostate cancer using three views of MRI monomodal: an axial, sagittal, and coronal plane. Table 1 shows the registration results of one patient dataset. The accuracy of registration has been compared between the automatically registered image that was done using MATLAB software and the gold-standard manual image that was done by experts. It can be concluded that there was no significant difference between the automatically and manually registered MRI monomodal images. Since this is only a pilot study, it can be used to notify the physician whether or which type of chemotherapy is helpful for a particular patient.

TABLE 1. Registration results on a 70-year-old patient.

Plane	Manual (Gold Standard) Image		Automatic Registered Image
	Time 1	Time 2	Time 1 + Time 2
Axial			



Mono-modal similarity measures can be used for the evaluation of the registration results. The procedure has been assessed to determine alignment accuracy based on the volume and registered distance between the images. The proposed method can obtain registration accuracy as predicted by the quantitative results. Tables 2 and 3 show the manual and automatic registration of 5 patients' calculations assessed based on root mean square error (RMSE) to determine the alignment accuracy. The MRI monomodal registered automatically and manually showed no discernible changes. As a result, the suggested method aids the doctor in diagnosing prostate cancer. It can offer crucial information about the disease's course and help them choose the appropriate medicines based on the patient's condition.

Table 2 shows the results of the distance of prostate cancer by manual calculation done by experts in five patients.

TABLE 2. Manual registration of prostate cancer.

t1			**t2**		
Axial	Coronal	Sagittal	Axial	Coronal	Sagittal
5.24cm	4.23cm	4.33cm	5.25cm	4.30cm	4.34cm

Table 3 shows the result distance of prostate cancer in three planar views of axial, coronal and sagittal using automatic registration calculation implemented in the MATLAB software of five patients.

TABLE 3. Automatic registration of prostate cancer.

t1			t2		
Axial	Coronal	Sagittal	Axial	Coronal	Sagittal
5.25cm	4.21cm	4.35cm	5.26cm	4.32cm	4.37cm

Table 4 shows the disease progression by manual registration distance and auto registration distance taken from Tables 3 and 4. The accuracy shown is equivalent to the manual (gold standard) registration distance by a specialist. The negative value represents that prostate cancer has shrunk in the distance.

TABLE 4. The difference between manual (gold standard) distance and automatic registration distance.

Manual registration distance [disease progression]			Auto registration distance [disease progression]		
ΔAxial	ΔCoronal	ΔSagittal	ΔAxial	ΔCoronal	ΔSagittal
0.10cm	0.70cm	0.10cm	0.10cm	1.10cm	0.20cm

Table 5 shows the prostate volume comparison between the manual and automatic registration using the standard ellipsoid formula as the proposed method. It shows the comparison of manual and automatic differences of about 0.22ml.

TABLE 5. The prostate volume comparison between manual and automatic determines the disease progression.

Manual Registration (ml)		Auto Registration (ml)		Progression Disease ($V_{t2} - V_{t1}$) (ml)	
V_{t1}	V_{t2}	V_{t1}	V_{t1}	V_{manual}	V_{auto}
46.85	45.82	46.65	45.40	−1.03	−1.25

The regression or progression of the tumour can be followed by the use of monomodal registration of serial examinations. These allow a quantitative contrast for longitudinal monitoring of disease progression or recession and postoperative follow-up. This registration method is applied to coronal, sagittal and axial views of prostate cancer from five patients. The automatic registration results distance is 0.10cm (axial), 1.10cm (coronal) and 0.20cm (sagittal) with progression disease using ellipsoid volume of 1.03ml. The differences in accuracy for the patients are shown in Tables 4 and 5. These accuracies of automatic registration are equivalent to a gold-standard manual calculation by an expert. There was no meaningful contrast between the automatically and manually registered MRI mono-modal from the patient. Therefore, the suggested method allows the physician to diagnose prostate cancer as it can provide important information about the disease progression and decide the necessary therapies regarding the patient's condition.

Secondly, the comparison of registered MRI images is applied to resolve whether a tumour is adequately treated before and immediately after therapy. It is incredibly crucial in situations where the oedematous response to treatment can be confused with a highly perfused tumour. Besides that, according to the volume calculation, the prostate using an ellipsoid formula explains that the patient has a volume of 46.85ml for time 1 and 45.82ml for time 2 as shown in Table 5. Furthermore, it shows that the cancer shrunked about 1.03ml, concluding that this patient undergoes excellent and adequate treatment during therapy.

While there is a wide range of research in monomodal medical image registration, there are some challenges that still face such a necessary process. One of the main issues facing the implementation of the registration process is the availability of the dataset. There are fewer data sets of prostate cancer in Malaysia, which restricts the possibility of comparing, generalizing and assessing the presented methods. In addition, there are a few difficulties with the registration in the pelvis and prostate, which are the abdomen having an irregular boundary compared to the head to which most of the registration has been applied. Next, the healthy prostate is a small organ that measures only about 25ml in its broadest dimension transversely beyond the base. Furthermore, confounding circumstances such as various patient positions as well as rectal and bladder fillings can hinder the registration process. In addition to the previously stated challenges, the current algorithm can be further improved by combining with machine learning techniques for better and fast results, such as detecting aortic valves [19], [20] and carpals bone [21].

CONCLUSION

The main purpose of this study is to register two MRI images from various acquisition times to facilitate the physician in monitoring the progression of the tumour in the patient's body. In this study, we proposed a monomodal registration of MRI images in three views, which are axial, coronal and sagittal, for five patients diagnosed with prostate cancer with another MR image with the same patient but at a different time. As a result, we can examine the evolution of the tumour inside the male reproductive system.

The monomodal registration can be utilized to notify the physician whether or which type of chemotherapy is useful for a particular patient. Furthermore, the registrations of images from various time frames might accurately identify the disease progression. In this study, MRI monomodal registration successfully investigated the tumour growth of prostate cancer. Registration was carried out using point feature-based registration methods that have been introduced. It employs feature control point-based and calculates the volume of the prostate to compare manual gold standard distance and automatically registered distance for accuracy testing. As a result, the registration performance gives a promising development as indicated by the evolution, growth and changes in the shape of cancer in five sets of patients from different acquisition times.

Nowadays, the only modality that can be used to evaluate bilobar or unilobar disease is MRI. It can also assess the extracapsular extension and seminal vesicle invasion and invasion of other adjacent structures, for instance, the bladder, rectum, external sphincter or pelvic wall. Based on the research, it can be concluded that the proposed method maintains excellent performance and operates adequately for monomodal medical image registration. In future work, we propose adding more respective data of patients with prostate cancer to test the algorithm so that the data can be more relevant, yielding more results. Moreover, investigation using intensified-based techniques and comparison with feature-based methods are recommendable for future work. Besides that, multimodal registration of MRI and ultrasound prostate cancer can demonstrate complete and advanced information when combining two different imaging modalities. This could also stand as future research.

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REFERENCES

1. S. K. Wong, N. V. Mohamad, T. R. Giaze, K. Y. Chin, N. Mohamed, and S. Ima-Nirwana, "Prostate cancer and bone metastases: The underlying mechanisms," *International Journal of Molecular Sciences*, vol. 20, no. 10. Multidisciplinary Digital Publishing Institute (MDPI), May 02, 2019.
2. D. A. Bader and S. E. McGuire, "Tumour metabolism and its unique properties in prostate adenocarcinoma," *Nature Reviews Urology*, vol. 17, no. 4. Nature Publishing Group, pp. 214–231, 2020.
3. M. N. Subahir, S. A. Shah, and Z. Md Zainuddin, "Risk factors for prostate cancer in Universiti Kebangsaan Malaysia Medical Centre: A case-control study," *Asian Pacific J. Cancer Prev.*, vol. 10, no. 6, pp. 1015–1020, 2009.
4. T. Penzkofer and C. M. Tempany-Afdhal, "Prostate cancer detection and diagnosis: The role of MR and its comparison with other diagnostic modalities - a radiologist's perspective," *NMR Biomed.*, vol. 27, no. 1, pp. 3–15, 2014.
5. S. Miah *et al.*, "A prospective analysis of robotic targeted MRI-US fusion prostate biopsy using the centroid targeting approach," *J. Robot. Surg.*, vol. 14, no. 1, pp. 69–74, 2020.
6. M. Arif *et al.*, "Clinically significant prostate cancer detection and segmentation in low-risk patients using a convolutional neural network on multi-parametric MRI," *Eur. Radiol.*, vol. 30, no. 12, pp. 6582–6592, 2020.
7. A. Sciarra *et al.*, "Advances in magnetic resonance imaging: How they are changing the management of prostate cancer," *European Urology*, vol. 59, no. 6. Elsevier, pp. 962–977, 2011.
8. A. Rahimi, A. Khalil, A. Faisal, and K. W. Lai, "CT-MRI Dual Information Registration for the Diagnosis of Liver Cancer: A Pilot Study Using Point-based Registration," *Curr. Med. Imaging Former. Curr. Med. Imaging Rev.*, vol. 18, no. 1, pp. 61–66, Aug. 2021.
9. A. Khalil *et al.*, "Brain Tumour Temporal Monitoring of Interval Change Using Digital Image Subtraction Technique," *Front. Public Heal.*, vol. 9, Sep. 2021.
10. P. Decazes, P. Hinault, O. Veresezan, S. Thureau, P. Gouel, and P. Vera, "Trimodality PET/CT/MRI and Radiotherapy: A Mini-Review," *Front. Oncol.*, vol. 10, no. February, pp. 1–9, 2021.
11. A. Khalil, S. C. Ng, Y. M. Liew, and K. W. Lai, "An Overview on Image Registration Techniques for Cardiac Diagnosis and Treatment," *Cardiology Research and Practice*, vol. 2018. 2018.

12. N. Al-Azzawi and W. Ahmed K. Wan Abdullah, “MRI Monomodal Feature-Based Registration Based on the Efficiency of Multiresolution Representation and Mutual Information,” *Am. J. Biomed. Eng.*, vol. 2, no. 3, pp. 98–104, Aug. 2012.
13. O. Ben Sassi, T. Delleji, A. Taleb-Ahmed, I. Feki, and A. Ben Hamida, “MR image monomodal registration using structure similarity index,” 2008.
14. N. C. Institute, “The Cancer Imaging Archive,” *The Cancer Imaging Archive*. p. 1, 2011, Accessed: Aug. 21, 2019. [Online].
15. A. Khalil, A. Faisal, S.-C. Ng, Y. M. Liew, and K. W. Lai, “Multimodality registration of two-dimensional echocardiography and cardiac CT for mitral valve diagnosis and surgical planning,” *J. Med. Imaging*, vol. 4, no. 03, p. 1, Aug. 2017.
16. A. A. Goshtasby, *2-D and 3-D Image Registration: For Medical, Remote Sensing, and Industrial Applications*. John Wiley and Sons, 2005.
17. A. Khalil, Y. M. Liew, S. C. Ng, K. W. Lai, and Y. C. Hum, “Echocardiography to cardiac CT image registration: Spatial and temporal registration of the 2D planar echocardiography images with cardiac CT volume,” 2016.
18. X. Zhuang, K. S. Rhode, R. S. Razavi, D. J. Hawkes, and S. Ourselin, “A registration-based propagation framework for automatic whole heart segmentation of cardiac MRI,” *IEEE Trans. Med. Imaging*, vol. 29, no. 9, pp. 1612–1625, Sep. 2010.
19. M. H. A. Nizar, C. K. Chan, A. Khalil, A. K. M. Yusof, and K. W. Lai, “Real-time Detection of Aortic Valve in Echocardiography using Convolutional Neural Networks,” *Curr. Med. Imaging Former. Curr. Med. Imaging Rev.*, vol. 16, no. 5, pp. 584–591, 2019.
20. M. H. bin A. Nizar, C. K. Chan, A. K. M. Yusof, A. Khalil, and K. W. Lai, “Detection of aortic valve from echocardiography in real-time using convolutional neural network,” in *2018 IEEE EMBS Conference on Biomedical Engineering and Sciences, IECBES 2018 - Proceedings*, pp. 91–95, 2019.
21. L. K. Meng *et al.*, “Carpal Bone Segmentation Using Fully Convolutional Neural Network,” *Curr. Med. Imaging Former. Curr. Med. Imaging Rev.*, vol. 15, no. 10, pp. 983–989, 2019.