

The Existence of a Topolinear Isomorphism on an infinite dimensional Hilbert Space H Corresponding to a Homeomorphism on it's Projective Space $P(H)$

Ebrahim Esrafilian

Department of Mathematics

Iran University of Science and Technology

Narmak, Tehran-16, Iran

Abstract

In this paper we prove a theorem which states the relationship between the topolinear isomorphisms on an infinite dimensional Hilbert Space H and the Homeomorphisms on projective Space $P(H)$. This theorem is proved by E.Artin in the finite dimensional case.

Key words: Topolinear Isomorphism, Hilbert Space, Homeomorphism, Projective.

Introduction

The following H is an infinite dimensional separable Hilbert Space and $P(H)$ is its projective space which is given a smooth structure as in [2]. We mean by $[x] \in P(H)$ the one dimensional vector subspace of H generated by $x \in \hat{H} = H - 0$.

$[x] + [y]$ means the two dimensional subspace generated by $x, y \in \hat{H}$. in fact $[z] \subset [x] + [y]$ means that there exists $a, b \in \hat{R}$ such that $z = ax + by$. and if $[z] \neq [x]$, There exists a unique $d \in \hat{R}$ such that $[z] = [x + dy]$. We quote some necessary statments from [2].

Proposition 1.1 *Let S be a unit sphere in a normed linear space B and $T : B \rightarrow B$ a linear bijection, and \tilde{T} be the induced bijection*

$$\tilde{T} : S \rightarrow S$$

defined by $\tilde{T}(u) = \frac{T(u)}{\|T(u)\|}$ for $u \in S \subset B$.

If T is a homeomorphism then \tilde{T} is also homeomorphism.

We are ready to state the theorem which is the main result of this paper

Proposition 1.2 *Let $f : P(H) \rightarrow P(H)$ be a topological isomorphism such that*

$$[x] \subset [y] + [z] \rightarrow f[x] \subset f[y] + f[z].$$

Then there exists a topological isomorphism $T : P(H) \rightarrow P(H)$ such that the induced transformation $\tilde{T} : P(H) \rightarrow P(H)$ agrees with f .

Proof. the hypothesis implies that if $[x] \subset [y] + [z]$ then $f^{-1}[x] \subset f^{-1}[y] + f^{-1}[z]$ and by induction on k , we get that if $[z] \subset [z_1] + \dots + [z_k]$ then $f[z] \subset f[z_1] + \dots + [z_k]$, and $f^{-1}[z] \subset f^{-1}[z_1] + \dots + f^{-1}[z_k]$.

Let $\{x_i\}$ be a Hamel basis for H where i is an arbitrary element of a set \mathcal{A} . It is clear that if $f[x_i] = [y_i]$ then $\{y_i\}$ is also a Hamel basis for H .

Now we choose an element of \mathcal{A} call it 1, then for any $i \neq 1$ the line

$$L_i = [x_1 + x_i] \subset [x_1] + [x_i]$$

where L_i is not coincide with $[x_i]$ or $[x_1]$, consequently

$$fL_i \subset [y_1] + [y_i]$$

and fL_i is not coincide with $[y_i]$ or $[y_1]$. Then, for some unique $d_i \in \mathbb{R}$ we have

$$fL_i = [y_1 + d_i y_i].$$

by choosing a suitable y_i we may assume that $d_i = 1$. Then

$$\text{for } i \in \mathcal{A}, \quad f[x_i] = [y_i] \quad (1)$$

$$\text{and for } i \neq 1, \quad f[x_1 + x_i] = [y_1 + y_i].$$

Now we choose another index from \mathcal{A} , call it 2. Then for $a \in \mathbb{R}$

$$L = [x_1 + ax_2] \subset [x_1] + [x_2] \quad \text{where } L \neq [x_2]$$

Therefore

$$fL \subset [y] + [y_2], \quad \text{where } fL \neq [y_2].$$

Then for a unique $a' \in \mathbb{R}$ we have

[Downloaded from system.knu.ac.ir on 2026-06-10]

Introduction

The following H is an infinite dimensional separable Hilbert Space and $P(H)$ is its projective space which is given a smooth structure as in [2]. We mean by $[x] \in P(H)$ the one dimensional vector subspace of H generated by $x \in \hat{H} = H - 0$. $[x] + [y]$ means the two dimensional subspace generated by $x, y \in \hat{H}$. In fact $[z] \subset [x] + [y]$ means that there exists $a, b \in \hat{R}$ such that $z = ax + by$. and if $[z] \neq [x]$, There exists a unique $d \in \hat{R}$ such that $[z] = [x + dy]$. We quote some necessary statements from [2].

Theorem 1.1 *Let S be a unit sphere in a normed linear space B and $T : B \rightarrow B$ a linear bijection, and \tilde{T} be the induced bijection*

$$\tilde{T} : S \rightarrow S$$

defined by $\tilde{T}(u) = \frac{T(u)}{\|T(u)\|}$ for $u \in S \subset B$. If \tilde{T} is a homeomorphism then T is also a homeomorphism.

We are ready to state the theorem which is the main result of this paper

Theorem 1.2 *Let $f : P(H) \rightarrow P(H)$ be a topological isomorphism such that*

$$[x] \subset [y] + [z] \rightarrow f[x] \subset f[y] + f[z].$$

Then there exists a topological isomorphism $T : P(H) \rightarrow P(H)$ such that the induced transformation $\tilde{T} : P(H) \rightarrow P(H)$ agrees with f .

Proof. the hypothesis implies that if $[x] \subset [y] + [z]$ then $f^{-1}[x] \subset f^{-1}[y] + f^{-1}[z]$ and by induction on k , we get that if $[z] \subset [z_1] + \dots + [z_k]$ then $f[z] \subset f[z_1] + \dots + f[z_k]$, and $f^{-1}[z] \subset f^{-1}[z_1] + \dots + f^{-1}[z_k]$.

Let $\{x_i\}$ be a Hamel basis for H where i is an arbitrary element of a set \mathcal{A} . It is clear that if $f[x_i] = [y_i]$ then $\{y_i\}$ is also a Hamel basis for H .

Now we choose an element of \mathcal{A} call it 1, then for any $i \neq 1$ the line

$$L_i = [x_1 + x_i] \subset [x_1] + [x_i]$$

where L_i is not coincide with $[x_i]$ or $[x_1]$, consequently

$$fL_i \subset [y_1] + [y_i]$$

and fL_i is not coincide with $[y_i]$ or $[y_1]$. Then, for some unique $d_i \in \mathbb{R}$ we have

$$fL_i = [y_1 + d_i y_i].$$

by choosing a suitable y_i we may assume that $d_i = 1$. Then

$$\text{for } i \in \mathcal{A}, \quad f[x_i] = [y_i] \quad (1)$$

$$\text{and for } i \neq 1, \quad f[x_1 + x_i] = [y_1 + y_i].$$

Now we choose another index from \mathcal{A} , call it 2. Then for $a \in \mathbb{R}$

$$L = [x_1 + ax_2] \subset [x_1] + [x_2] \text{ where } L \neq [x_2]$$

Therefore

$$fL \subset [y] + [y_2], \text{ where } fL \neq [y_2].$$

Then for a unique $a' \in \mathbb{R}$ we have

[Downloaded from system.knu.ac.ir on 2026-06-10]

Now we define

$$\mu : R \longrightarrow R$$

by $\mu(a) = a'$ and we will show that μ is the identity function on R . Since

$$[x_1 + ax_2] \neq [x_1 + bx_2] \text{ if } a \neq b$$

it follows that $a' \neq b'$, then μ is injective. We have also from (1) that

$$0' = 0 \text{ and } 1' = 1. \quad (2)$$

Now, we will show that for any $i \in \mathcal{A}$

$$f[x_1 + ax_i] = [y_1 + a'y_i]$$

For any fixed $i \neq 1, 2$ in \mathcal{A} we have

$$f[x_1 + ax_i] = [y_1 + by_i].$$

On the other hand $L = [ax_2 - ax_i] \subset [x_2] + [x_i]$ with $L \neq [x_i]$, and so $fL \subset [y_2] + [y_i]$ with $fL \neq [y_i]$. Consequently, $fL = [y_2 + dy_i]$ for some unique d . On the other hand,

$$L \subset [x_1 + ax_2] + [x_1 + ax_i] \text{ with } L \neq [x_1 + ax_i].$$

Then as before $fL = ([y_1 + a'y_2] + d'(y_1 + by_i))$ and it follows that $d = -\frac{b}{a'}$. But

$$L \subset [x_1 + x_2] + [x_1 + x_i] \text{ with } L \neq [x_1 + x_i]$$

and by (1)

$$fL \subset [y_1 + y_2] + [y_1 + y_i] \text{ with } fL \neq [y_1 + y_i]$$

Then for some unique h we have $fL = [y_1 + y_2 + h(y_1 + y_i)]$, consequently $d = -1$ and $b = a'$, then for all $i \in \mathcal{A}$ and $a \in R$ we have

$$f[x_1 + ax_i] = [y_1 + a'y_i]. \quad (3)$$

Now we are going to prove that μ is surjective. Choose a finite number of n vectors of \mathcal{A} including x_1 and x_2 say x_1, x_2, \dots, x_n . Then by induction we have

$$f[x_1 + a_2x_2 + \dots + a_nx_n] = [y_1 + a'_2y_2 + \dots + a'_ny_n]$$

and it follows that

$$f[a_2x_2 + \dots + a_nx_n] = [a'_2y_2 + \dots + a'_ny_n].$$

[1] page 90.

Let $L = [y_1 + by_2]$ be a point of $P(H)$, since f is bijective, then there exists some $v \in \dot{H}$ such that $L = f[v]$, then v can be written as a linear combination of x_j including x_1, x_2 . For this purpose we can use the above set x_1, x_2, \dots, x_n then

$$v = \alpha_1x_1 + \alpha_2x_2 + \dots + \alpha_nx_n.$$

By (5) we have $\alpha_1 \neq 0$ and consequently,

$$L = f[x_1 + \beta_2x_2 + \dots + \beta_nx_n] \text{ with } \beta_j = \frac{\alpha_j}{\alpha_1}$$

Then by (4) $\beta'_2 = b$ and consequently μ is surjective.

To show that $\mu(a + b) = \mu(a) + \mu(b)$ we consider the line $L = [x_1 + (a + b)x_2 + x_3]$. Then by (2) and (3) we have

$$fL = [y_1 + (a + b)'y_2 + y_3]$$

but

$$L \subset [x_1 + ax_2] + [bx_2 + x_3] \text{ and } L \neq [bx_2 + x_3].$$

By (4) and (5)

$$fL \subset [y_1 + a'y_2] + [by_2 + y_3]$$

and so $fL = [(y_1 + a'y_2) + \lambda(b'y_2 + y_3)]$ for some λ . It follows that $\lambda = 1$ and so

$$\mu(a + b) = (a + b)' = a' + b' = \mu(a) + \mu(b). \quad (6)$$

Similarly by considering a line $[x_1 + (ab)x_2 + x_3]$, we get

$$\mu(ab) = \mu(a) \cdot \mu(b) \quad (7)$$

Thus μ is a bijective mapping satisfying (2), (6) and (7) and therefore it is the identity mapping on R . Consequently

$$f[a_1x_1 + \dots + a_kx_k] = [a_1y_1 + \dots + a_ky_k]. \quad (8)$$

The equation (8) has been derived by fixing x_1, x_2 from the Hamel basis $\{x_i\}$. Since it still holds for a_1, a_2 zeros, it follows that (8) is true for any finite combination of vectors in $\{x_i\}$.

If $x \in H$, then $x = \sum a_i x_i$ (a finite sum) and so we define a linear map

$$T: H \longrightarrow H \text{ by } T(x) = \sum a_i y_i$$

then T is also a bijection and it induces a map

$$\bar{T}: P(H) \longrightarrow P(H)$$

$$\bar{T}[x] = [T(x)] = [\sum a_i y_i] = f[x]$$

Consequently, \bar{T} agrees with f .

Let the bijection $\tilde{T}: S \longrightarrow S$ defined by T as in Theorem 1.1 is a homeomorphism. This follows from the commutative diagram

$$\begin{array}{ccc} P(H) & \xrightarrow{f} & P(H) \\ \phi \uparrow & & \uparrow \phi \\ S & \xrightarrow{\tilde{T}} & S \end{array} \quad (9)$$

because f is supposed a homeomorphism and ϕ is the local diffeomorphism between S and $P(H)$, it follows from Theorem 1.1 that \tilde{T} is a

References

- [1] Artins.E. Geometric Algebra, Interscience, 1957.
- [2] Esrafilian.E. Some properties of projective space and unit sphere on an Infinite dimensional Hilbert Space, proceedings of 24th Annual Mathematical Conference of Iran, 1992.
- [3] Gallot.S. Hulin.D. and Lafon.J. Taine Riemannian Geometry, Springer Verlag, 1990.
- [4] Jardine.J.F. and Smith.V.P. Algebraic K-Theory Connection with Geometry and Topology Nato Asi. series 1987.
- [5] Lang.S. Introduction to Differential Manifolds, Springer Verlag, 1985.