FIXED POINT THEOREMS FOR MULTIVALUED APPROXIMABLE MAPPINGS

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ABSTRACT. In this paper we introduce several classes of multivalued approximable mappings and develop the fixed point theory for these mappings acting in a cone. As an important special case we have the theory of k-ball-contractive perturbations of strongly pseudo-contractive and accretive mappings.

1. Introduction. Since the early 1960's several important classes of nonlinear noncompact mappings have been introduced among which are monotone type, condensing and A-proper mappings. The first two classes of mappings have been extensively studied also in the multivalued case by many authors, while the class of multivalued A-proper mappings has been first extensively studied in the author's thesis (1975) and his subsequent work and then jointly by the author and Petryshyn (see, e.g., [7], [8], [9]). It turns out that multivalued mappings play an important role in the theory of evolution equations, variational inequalities, contingent ordinary, partial differential and integral equations, optimal control theory, etc.

The purpose of this paper is to introduce and study several new classes of multivalued approximable mappings acting in a cone. A portion of these results pertaining to Pγ-compact mappings have been obtained in the author's Ph.D. thesis [7]. All our results are of the constructive nature as defined below. Applications of these results to boundary value problems for differential equations will be given in a subsequent paper.

2. Fixed point theorems for approximable mappings. We begin this section by introducing the classes of mappings to be studied in the sequel. Let X be a normed linear space and \( \{X_n\} \) a sequence of oriented finite dimensional Banach spaces such that \( \dim X_n \to \infty \) as \( n \to \infty \). Suppose that for each n there exists a linear mapping \( V_n \) from \( X_n \) into \( X \) such that for some constant \( C > 0 \), \( \|V_n x\| \leq C \|x\| \) for all \( x \in X_n \) and all \( n \). The pair \( \{X_n, V_n\} \) is referred to as an approximation scheme for \( X \).

Definition 1. If \( X_n \subset X \), \( P_n: X \to X_n \) is a continuous linear projection onto \( X_n \) such that \( P_n x \to x \) in \( X \) as \( n \to \infty \) for each \( x \in X \) and \( V_n \) is the identity...
injection of $X_n$ into $X$, then the triple of sequences $\Gamma = \{X_n, V_n, P_n\}$ is said to be a projectionally complete scheme for $X$.

Such a scheme always exists if $X$ has a Schauder basis. Our first class of multivalued mappings is given by

**Definition 2.** A multivalued mapping $T: D \subset X \to 2^X$ is said to be approximately compact ($A_\gamma$-compact for short) with respect to the scheme $\{X_n, V_n\}$ if

1. there exists a sequence of upper semicontinuous mappings $\{T_n\}$ from $D_n \subset X_n$ into $\mathcal{C}(X_n) = \text{the family of all nonempty compact and convex subsets of } X_n$;

2. there exists $\gamma > 0$ such that, if for some positive $\mu > \gamma$ and a sequence $(x_n, x_n) \in D_n$ with $\|x_n\| < M$ for all $k$ and some $M > 0$, we have that $V_n(x_n - \mu x_n) \to f$ as $k \to \infty$ in $X$ for some $y_n \in T_n(x_n)$ and $f$ in $X$, then there exist a subsequence $(x_{n_k})$ and $x_0 \in X$ such that $V_{n_k}(x_{n_k}) \to x_0$ in $X$ and $f \in T(x_0) - \mu x_0$.

When Definition 2 holds with $f$ given in advance, we say that $T$ is $A_\gamma$-compact at $f$.

**Definition 3.** We say that $T: D \subset X \to 2^X$ is projectionally compact ($P_\gamma$-compact for short) w.r.t. a projectionally complete scheme $\Gamma = \{X_n, V_n, P_n\}$ if $T, T_n = P_n T$ and $D_n = D \cap X_n$ satisfy all the conditions in Definition 2. Moreover, if condition (2) holds only for $\mu = 1$, $T - I$ is said to be $A$-proper w.r.t. $\Gamma$.

**Remark.** $P_\gamma$-compact single-valued mappings were introduced by Petryshyn [10] and by Milojevic [7] in the multivalued case. A slight variant of the definition of $A_\gamma$-compact mappings at 0 in the single-valued case was given in Lees-Schultz [6].

In [7] we have shown that if $T: D \subset X \to 2^X$ is either ball-condensing or $k$-contractive, generalized contractive or monotone, then $T$ is $P_\gamma$-compact. Moreover, perturbations of $P_\gamma$-compact mappings by compact multivalued ones are also $P_\gamma$-compact. We shall also need the following special case of Proposition 2.1 in [8].

**Example 1** [8]. Let $X$ be a Banach space with a projectionally complete scheme $\Gamma = \{X_n, V_n, P_n\}$, $\|P_n\| < 1$, $T: X \to X$ continuous, surjective and $a$-stable, i.e. for some $c > 0$, $\|P_n T x - P_n T y\| > c \|x - y\|$ for all $x, y \in X_n$ and $n \geq 1$ and $F: D \subset X \to X$ demicontinuous and $k$-ball-contractive [17] with $k < c$ or ball-condensing if $c = 1$. Then $T + F$ is $A$-proper. In particular, as $T$ we can take a $c$-strongly accretive map, i.e. $(Tx - Ty, x - y)_+ = \sup \{(Tx - Ty, u) | u \in J(x - y)\} > c \|x - y\|^2$, $x, y \in X$, where $J$ is the normalized duality map.

By a cone $K \subset X$ we mean a closed subset of $X$ such that $\alpha x + \beta y \in K$ whenever $x, y \in K$ and $\alpha > 0, \beta > 0$. We denote by $B(0, r)$ and $B_n(0, r)$ the open balls in $X$ and $X_n$ respectively centered at the origin and of radius $r$; $\partial_K(B \cap K)$ denotes the boundary of $B$ relative to $K$.

Our first fixed point result for positive $A_\gamma$-compact mappings is given by
Theorem 1. Let $X$ be a Banach space, $K$ and $K_n$ cones in $X$ and $X_n$ respectively, $D \subset X$ and $D_n \subset X_n$ open and bounded subsets containing the origin of $X$ and $X_n$ respectively and $T: D \cap K \to 2^K$ $A_\gamma$-compact at 0 with $T_n: D_n \cap K_n \to CK(K_n)$. Suppose that $(D_n)$ is uniformly bounded, i.e., there exists an $M > 0$ such that $\|x\| \leq M$ for all $x \in D_n$ and all $n$, and that $T_n$ satisfies the Leray-Schauder condition on $\partial_K(D_n \cap K_n)$, i.e., for all large $n$

$\alpha \in T_n(x)$ for all $x \in \partial_K(D_n \cap K_n)$ and $\alpha > \mu$ for some positive $\mu > \gamma$.

Then the equation $\mu x \in T(x)$ is feebly approximation solvable, i.e., for sufficiently large $n$, each equation $\mu x \in T_n(x)$ has a solution $x_n \in D_n \cap K_n$ and there exists a subsequence $\{x_{n_k}\}$ such that $V_n(x_{n_k}) \to x_0$ with $\mu x_0 \in T(x_0)$. If the equation $\mu x \in T(x)$ is uniquely solvable, then it is strongly approximation solvable in the sense that the entire sequence $V_n(x_n) \to x_0$ with $\mu x_0 \in T(x_0)$.

Proof. For a large $n$ define a mapping $H_n: [0, 1] \times (D_n \cap K_n) \to CK(K_n)$ by $H_n(t, x) = t/\mu T_n(x)$. It is easy to see that $H_n$ is u.s.c. compact and $x \notin H_n(t, x)$ for all $x \in \partial_K(D_n \cap K_n)$ and $t \in [0, 1]$ and by the homotopy theorem for the generalized fixed point index [2] $i_K(1/\mu T_n, D_n) = i_K(0, D_n) = 1$, where $0$ is the zero mapping. Hence, for all large $n$ there exists $x_n \in D_n \cap K_n$ such that $\mu x_n \in T_n(x_n)$. Since $\|x_n\| \leq M$ for all $n$ and $V_n(y_n - \mu x_n) = 0$ for $y_n \in T_n(x_n)$ with $\mu x_n = y_n$, by the $A_\gamma$-compactness of $T$ at 0 some subsequence $V_n(x_{n_k}) \to x_0 \in K$. Since $\|V_n(x_n)\| \leq C_1\|x_n\| \leq C_1 M$, $x_0 \in B(0, C_1 M)$. Arguing by contradiction, the second assertion follows easily from the unique solvability.

Theorem 2. Let $X$, $K$ and $K_n$ be as in Theorem 1 and $T: K \to 2^K$ $A_\gamma$-compact at 0 with $T_n: K_n \to CK(K_n)$ such that:

1. there exists a $C_2 > 0$ such that $\|V_n(x)\| \geq C_2\|x\|$ for all $n$ and all $x \in X_n$;
2. there exists an $r_0 > 0$ such that $T$ satisfies the Leray-Schauder condition (\mu) on $\partial_K(B(0, r) \cap K)$ for all $r \in [r_0, C_1 r_0 / C_2]$ and some positive $\mu > \gamma$;
3. there exists a $C_3 > 0$ such that $\lambda \in T_n(x)$ for some $x \in \partial_K(B_n(0, r_0 / C_2) \cap K_n)$ and all $n$, then $0 < C_3$.

Then the equation $\mu x \in T(x)$ is feebly approximation solvable in $B(0, C_1 r_0 / C_2) \cap K$ with approximate solutions lying in $B_n(0, r_0 / C_2) \cap K_n$ and is strongly approximation solvable if uniquely solvable.

Proof. In view of Theorem 1, it suffices to show that $T_n$ satisfies the Leray-Schauder condition on $\partial_K(B_n(0, r_0 / C_2) \cap K_n)$ for all large $n$. We proceed by contradiction. Suppose that for some sequences $\{x_{n_h} \mid x_{n_h} \in \partial_K(B_n(0, r_0 / C_2) \cap K_n)\}$ and $\{\lambda_{n_h} \mid \lambda_{n_h} > \mu\}$ we have $\lambda_{n_h} x_{n_h} \in T_n(x_{n_h})$. By (\lambda) we may assume that $\lambda_{n_h} \to \lambda \in [\mu, C_3]$ which, together with $\|x_{n_h}\| = r_0 / C_2$, implies that

$\|V_{n_h}(\lambda_{n_h} x_{n_h} - \lambda x_{n_h})\| = |\lambda_{n_h} - \lambda| \cdot \|V_{n_h}(x_{n_h})\| < |\lambda_{n_h} - \lambda| \cdot C_1 r_0 / C_2 \to 0$
theorem \( i_{K_n}(1/\mu)T_n U_n = i_{K_n}(1/\mu)T_n + \lambda h_n, U_n \neq 0 \). Thus, there exists \( x_1 \in U_n \) such that \( x_1 \in (1/\mu)T_n x_1 + \lambda h_n \) for each \( \lambda > 0 \). Take \( \lambda_k \to \infty \) and observe that \( \lambda_k h_n \in (x_1 - (1/\mu)T_n x_1) \) with \( \lambda_k ||h_n|| \to \infty \) as \( k \to \infty \). This contradicts the boundedness of \( (I - (1/\mu)T_n(U_n) \) and consequently, \( i_{K_n}(1/\mu)T_n U_n = 0 \). Next, using the homotopy \( F_n(t, x) = (t/\mu)T_n(x), x \in D_n \), we get that \( i_{K_n}(1/\mu)T_n, D_n = 1 \) and by the additivity theorem \( i_{K_n}(1/\mu)T_n U_n \backslash \bar{D}_n = -1 \). Thus, for all large \( n \) there exists \( x_n \in (U_n \backslash \bar{D}_n) \cap K_n \) such that \( \mu x_n \in T_n(x_n) \). Since \( ||x_n|| < M_1 \) for all \( n \), the \( A_\gamma \)-compactness of \( T \) at 0 imply that some subsequence \( V_n(x_n) \to x_0 \) with \( \mu x_0 \in T(x_0) \). By condition (1), \( x_0 \neq 0 \). □

The following result provides some conditions on \( T \) and \( T_n \) which imply conditions \((\mu)\) and \((\beta_n)\).

**Theorem 5.** Let \( X, K \) and \( K_n \) be as in Theorem 1 and \( T: K \to 2^K \) be \( A_\gamma \)-compact with \( T_n: K_n \to \mathcal{C}(K_n) \). Suppose that conditions (1), (2) and (3) of Theorem 2 hold and that there exists \( R_0 > C_1r_0/C_2 \) such that for each \( R \in [R_0, C_1r_0/C_2] \) we have

\( (\beta) \) there exists \( 0 \neq h_0 \in K \) such that \( x \in (1/\mu)T(x) + \beta h_0 \) for all \( x \in \partial_K(B(0, R) \cap K) \) and \( \beta > 0 \);

\( (\tau) \) there exist a \( C_4 > 0 \) and \( 0 \neq h_n \in K_n \) with \( V_n(h_n) \to h_0 \) such that if \( x \in (1/\mu)T_n(x) + \tau h_n \) for \( x \in \partial_K(B_n(0, R_0/C_2) \cap K_n) \) and all \( n \), then \( \tau < C_4 \).

Then the equation \( \mu x \in T(x) \) is feebly approximation solvable in \( B(0, C_1r_0/C_2) \backslash B(0, r_0) \).

**Proof.** As in Theorem 2 we get an \( n_0 > 1 \) such that \( T_n \) satisfies the Leray-Schauder condition \((\mu)\) on \( \partial_K(B_n(0, r_0/C_2) \cap K_n) \) for each \( n > n_0 \). To show that \((\beta_n)\) of Theorem 4 holds on \( \partial_K(B_n(0, R_0/C_2) \cap K_n) \) for all \( n > n_1 \) (> \( n_0 \)), we argue by contradiction. If such an \( n_1 \) did not exist, we could find \( \{x_n, x_n \in \partial_K(B_n(0, r_0/C_2) \cap K_n)\} \) and \( \{\beta_n > 0\} \) such that \( x_n \in (1/\mu)T_n(x_n) + \beta_n h_n \). By \((\tau)\) we can assume that \( \beta_n \to \beta \in [0, C_4] \) and let \( y_n \in T_n(x_n) \) be such that \( x_n = (1/\mu)y_n + \beta_n h_n \). Then \( V_n(y_n - \mu x_n) = -\mu \beta_n V_n(h_n) \to -\mu \beta h_0 \) and by the \( A_\gamma \)-compactness of \( T \), some subsequence \( V_{n(k)}(x_{n(k)}(x_{n(k)})) \to x_0 \) with \( -\mu \beta h_0 \in T(x_0) - \mu x_0 \) and \( R_0 < ||x_0|| < C_1R_0/C_2 \) by the properties of \( \{V_n\} \). Thus, \( x_0 \in (1/\mu)T(x_0) + \beta h_0 \) with \( \beta > 0 \) and \( R_0 < ||x_0|| < C_1R_0/C_2 \), in contradiction to \((\beta)\) and consequently, an \( n_1 \) with the above property exists. The conclusion of our theorem now follows from Theorem 4. Moreover, since the approximate solutions \( x_n \in B_n(0, R_0/C_2) \backslash B_n(0, r_0/C_2) \), we have \( r_0 < C_2||x_n|| < ||V_n(x_n)|| < C_1||x_n|| < C_1R_0/C_2 \) and consequently, the solution \( x_0 \) of \( \mu x \in T(x) \) satisfies \( r_0 < ||x_0|| < C_1R_0/C_2 \). □

As a consequence of Theorems 4 and 5, we have

**Corollary 6**[7]. Let \( X \) be a Banach space with a projectionally complete scheme \( \Gamma, K \subset X \) a cone and \( D_1 \subset D_2 \subset X \) two open and bounded sets with \( 0 \in D_1 \). Suppose that \( T: D_2 \cap K \to 2^K \) is \( P_\gamma \)-compact with \( P_\gamma T: D_2 \cap K_n \to
Corollary 1 with \( \mu \geq 1 \), the equation \( Tx + Fx = \mu x \) is f.a. solvable.

(b) If \( k_1 = 1 - k \) with \( k < 1 \) in (a) and also \( (\mu I - T - F)(D \cap K) \) is closed, the equation \( Tx + Fx = \mu x \) is solvable.

(c) In particular, if \( T = I - A \) in (a) (or (b)) with \( A : X \rightarrow X \) c-strongly accretive, \( k < c \) or \( F \) is ball-condensing if \( c = 1 \) (or \( k = c \) with \( c \geq 0 \)), \( (I - A - F)(K) \subset K \) and \( I - A - F \) satisfies conditions (1) and (2) of Corollary 1 with \( \mu = 1 \) (and \( (A + F)(D \cap K) \) is closed), then \( Ax + Fx = 0 \) is f.a. solvable (solvable).

In case when \( D \) does not contain 0, we have

**Theorem 3** [7]. Let \( X \) be a Banach space with a projectionally complete scheme \( \Gamma \) and \( D \subset X \) open and bounded. Suppose that \( T : \overline{D} \rightarrow 2^X \) is \( P \)-compact with \( P_n T : D \cap X_n \rightarrow CK(X_n) \) u.s.c. and satisfies:

1. if for some \( x_0 \in D \), \( \lambda(x - P_n x_0) \in P_n T(x) - P_n(x_0) \) for some \( x \in D_n \) and all large \( n \), then \( \lambda < C \) for some \( C > 0 \);
2. \( a(x - x_0) \notin T(x) - x_0 \) for \( x \in D \) and \( a > 1 \).

Then the equation \( x \in T(x) \) is feebly approximation solvable.

The proof of this theorem is based on the degree theory for multivalued compact mappings. The single-valued case of Theorem 3 is a slightly corrected version of Theorem 4.4 in [13]. In particular, we have

**Corollary 5.** Let \( X, D \) and \( \Gamma \) be as in Theorem 3, \( \|P_n\| < 1 \), \( T : X \rightarrow X \) and \( F : \overline{D} \rightarrow X \) as in Corollary 4 (a) (or (c)) and \( T + F(I - A - F) \) satisfies conditions (1) and (2) of Theorem 3 with \( \mu = 1 \).

Then the equation \( Tx + Fx = x \) (\( Tx + Fx = 0 \)) is f.a. solvable.

This result could be also extended to cover the cases (b) and (c) with \( k = c > 0 \) in Corollary 4.

Finally, we now provide some results involving nonzero solutions of \( px \in T(x) \).

**Theorem 4.** Let \( X, K, K_n, D \) and \( D_n \) be as in Theorem 1 and condition (1) of Theorem 2 hold. Let \( U \subset X \) and \( U_n \subset X_n \) be open and such that \( D \subset U \), \( B_n(0, r) \subset D_n \subset U_n \) for some \( r > 0 \) and \( \{U_n\} \) uniformly bounded by some constant \( M_1 > 0 \). Suppose that \( T : \overline{U} \cap K \rightarrow 2^K \) is \( A \)-compact at 0 and satisfies condition (\( \mu \)) of Theorem 1 on \( \partial_{K_n}(D_n \cap K_n) \) and for each large \( n \)

\( (\beta_n) \) there exists \( 0 \neq h_n \in K_n \) such that

\[ x \notin (1/\mu) T_n(x) + \beta h_n \text{ for all } \beta > 0 \text{ and } x \in \partial_{K_n}(U_n \cap K_n). \]

Then the equation \( \mu x \in T(x) \) is feebly approximation solvable in \( U \cap K \setminus \{0\} \).

**Proof.** We first show that for all large \( n \) the fixed point index \( i_{K_n}((1/\mu) T_n, U_n) = 0 \). Suppose that for some large \( n, i_{K_n}((1/\mu) T_n, U_n) \neq 0 \) and define \( H_n : [0, 1] \times (\overline{U_n} \cap K_n) \rightarrow CK(K_n) \) by \( H_n(t, x) = (1/\mu) T_n x + t \lambda h_n \) with \( \lambda > 0 \).

Then \( x \notin H_n(t, x) \) for \( t \in [0, 1] \) and \( x \in \partial_{K_n}(U_n \cap K_n) \) and by the homotopy
as \( k \rightarrow \infty \). By the \( A_{\gamma} \)-compactness of \( T \) at 0, a subsequence \( V_{n_{\omega}}(x_{n_{\omega}}) \rightarrow x_0 \)
with \( \lambda x_0 \in T(x_0) \), and the properties of \( V_n \) imply that \( r_0 < \|x_0\| \leq C_1 r_0/C_2 \),
in contradiction to (2). The conclusions of our theorem now follow from
Theorem 1 by taking \( B(0, r_0/C_2) \) and \( B_n(0, r_0/C_2) \) as \( D \) and \( D_n \).  

**Remark.** Condition (\( \lambda \)) in Theorem 2 is satisfied if for each real number \( R \)
there is a constant \( C(R) > 0 \) such that \( \|u\| \leq C(R) \) for all \( u \in T_n(x) \) with
\( \|x\| = R, \ x \in K_n \) and all \( n \).

**Remark.** When \( K = X, K_n = X_n, \mu = 1, D \) and \( D_n \) are balls and \( T \) and \( T_n \)
are single-valued, Theorems 1 and 2 were proved by Lees-Schultz [6] for their
\( A_{\gamma} \)-compact mappings and extend a theorem of Petryshyn [10]. We add that
their arguments required the convexity of \( D \) and \( D_n \).

**Corollary 1** [7]. Let \( X \) be a Banach space with a projectionally complete
scheme \( \Gamma = \{X_n, V_n, P_n\}, K \subset X \) a cone, \( K_n = K \cap X_n \) and \( D \subset X \) open
and bounded with \( 0 \in D \). Let \( T: \overline{D} \cap K \rightarrow 2^X \) be \( P_{\gamma} \)-compact at 0 with \( P_n T:
\overline{D} \cap K_n \rightarrow CK(X_n) \) u.s.c. and \( P_n(K) \subset K \) for all large \( n \). Suppose that:
(1) \( T \) satisfies the Leray-Schauder condition (\( \mu \)) on \( \partial_X(D \cap K) \);
(2) \( P_n T \) satisfies condition (\( \lambda \)) of Theorem 2 on \( \partial_X(D_n \cap K_n) \) for all large \( n \).
Then the equation \( \mu x \in T(x) \) is feebly approximation solvable in \( D \cap K \) and
strongly approximation solvable if uniquely solvable.

As consequences of this result we just mention here the following ones
(many others can be found in [7]).

**Corollary 2** [7]. Let \( X \) be a reflexive \( \pi_1 \)-Banach space, \( K, D \) and \( \Gamma \) as in
Corollary 1. Suppose that \( T: K \rightarrow CK(K) \) is a generalized contraction (i.e., for
each \( x \in K \) there exists \( \alpha(x) \in (0, 1) \) such that \( \delta(Tx, Ty) < \alpha(x)\|x - y\| \) for
all \( x, y \in K \), where \( \delta \) is the Hausdorff distance induced by the norm of \( X \)) and
\( C: \overline{D} \rightarrow CK(K) \) demiclosed and compact. Then, if \( T + C \) satisfies condition (\( \mu \))
on \( \partial_X(D \cap K) \) for some \( \mu > 1 \), the equation \( \mu x \in T(x) + C(x) \) is feebly
approximation solvable and is strongly approximation solvable if uniquely solvable.

**Corollary 3** [7]. Let \( X \) be a reflexive \( \pi_1 \)-Banach space and \( T: X \rightarrow CK(X) \)
a generalized contraction. Then for each \( f \in X \) the equation \( f \in x - Tx \) is
feebly approximation solvable in \( B(0, r_f) \) with \( r_f = \max\{\|v + f\|: \ v \in T(0)\}/(1 - \alpha(0)) \).

For the single-valued case with \( K = X \) and \( T: X \rightarrow X \) or \( T: D \rightarrow D \) see [1]
and the references therein. Moreover if \( T \) is \( k \)-strict contractive, \( k < 1 \),
Corollaries 2 and 3 hold without the reflexivity of \( X \) (cf. also [14]).

**Corollary 4.** (a) Let \( X, K, D \) and \( \Gamma \) be as in Corollary 1, \( \|P_n\| < 1 \), \( T: X \rightarrow X \) continuous \( k \)-strongly pseudo-contractive, i.e. \( \inf\{(Tx - Ty, x - y) \} = \inf\{(Tx - Ty, u)\|u \in J(x - y) \} \leq k\|x - y\|^2 \) for \( x, y \) in \( X \), with \( T(K) \subset K \)
and \( F: \overline{D} \cap K \rightarrow K \) continuous and \( k_1 \)-ball-contractive with \( k_1 < 1 - k \) or
ball-condensing if \( k = 0 \). Then, if \( T + F \) satisfies conditions (1) and (2) of
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$\CK(X_n)$ u.s.c. and $P_n(K) \subset K$ for all large $n$. Suppose also that $T$ satisfies conditions $(\mu)$ and $(\lambda)$ on $\partial_K(D_1 \cap K)$ and $\partial_K(D_1 \cap K_n)$ respectively and conditions $(\beta)$ and $(\tau)$ on $\partial_K(D_2 \cap K)$ and $\partial_K(D_2 \cap K_n)$ respectively. Then the equation $\mu x \in T(x)$ is feebly approximation solvable in $(D_2 \setminus D_1) \cap K$.

Remark. Theorem 4 is valid if condition $(2)$ holds on $\partial_K(U_n \cap K_n)$ and condition $(\beta_n)$ holds on $\partial_K(D_n \cap K_n)$, while Theorem 5 is also valid if condition $(\beta)$ holds on $\partial_K(B(0, r) \cap K)$ for each $r \in [r_0, C_1 r_0 / C_2]$, $(\tau)$ holds on $\partial_K(B_n(0, r_0 / C_2) \cap K_n)$, $(\mu)$ holds on $\partial_K(B(0, R) \cap K)$ for each $R \in [R_0, C_1 r_0 / C_2]$ and $(\lambda)$ holds on $\partial_K(B_n(0, R_0 / C_2) \cap K_n)$. The same observation applies to Corollary 4. For some existence results for positive single-valued $P$-compact mappings see [4], [5] (see also [17], [2] and the references therein). In particular, Corollary 6 is applicable to the mappings considered in Corollary 4.

Analyzing the proofs of Theorems 1 and 4, we see that just the solvability assertion for $\mu x \in T(x)$ still holds for the following larger class of mappings.

Definition 4. A multivalued mapping $T: D \subset X \to 2^X$ is said to be pseudo-$A_\gamma$-compact if condition $(1)$ of Definition 2 holds and there exists $\gamma > 0$ such that for some positive $\mu > \gamma$ and a sequence $\{x_n| x_n \in D_n\}$ with $\|x_n\| < M$ for all $n$ and some $M > 0$ we have that $V_n(y_n - \mu x_n) = 0$ for some $y_n \in T_n(x_n)$, then there exists $x \in D$ such that $\mu x \in T(x)$.

If $\Gamma = \{X_n, V_n, P_n\}$ is a projectionally complete scheme for $X$, then we can take $P_n T$ as $T_n$, in which case we obtain the so-called $G$-mappings of Figueiredo [3] with $T$ single-valued and $\mu = 1$. Various examples of such mappings (some of which are not $P_1$-compact) can be found in [3]. We add that for quite many of these examples one can show that the above sequence $\{x_n\}$ in Definition 4 has a subsequence weakly converging to a solution of $\mu x \in T(x)$ (see [12], [8] where a related notion of pseudo $A$-properness is considered). Finally, using the degree theory, one can establish the following:

Theorem 6. Let $X$ and $\Gamma$ be as in Corollary 4, $T: X \to X$ continuous and $F: \overline{B}(0, r) \subset X \to X$ demicontinuous and $k$-ball-contractive such that either $(I - T - F)(\partial B) \subset B$ or $(T x + F x, u) > 0$ for $u \in J(x), x \in \partial B$.

(a) If $T$ is surjective, a-stable and either $k < c$ or $F$ is ball-condensing if $c = 1$, the equation $Tx + Fx = 0$ is f.a. solvable.

(b) If $T_1 = T + eI$ is surjective for $\varepsilon > 0$, $T$ and $T_1$ are a-stable with $c_\varepsilon > c$ ($c_\varepsilon$ is the constant of a-stability of $T_\varepsilon$), $k = c$ and $(T + F)(\overline{B})$ is closed, then $Tx + Fx = 0$ is solvable.

(c) If $T_\varepsilon$ is a-stable and surjective for $\varepsilon > 0$ with $c_\varepsilon \to 0$ as $\varepsilon \to 0$, $F$ is compact and $(T + F)(\overline{B})$ is closed, then $Tx + Fx = 0$ is solvable.

Remark. As $T$ and $F$ in Theorem 6 one can take the mappings $A$ and $F$ considered in Corollary 4 (c) or $T = I - A$ with $A$ and $F$ as in Corollary 4(a) and (b) with either $(Ax + Fx, u) < \|x\|^2$ for $u \in J(x), x \in \partial B$ or $(I - A - F)(\partial B) \subset B$. Here and in all above results one can allow $F$ to be multivalued.
This theory of \( k \)-ball-contractive perturbations of (strongly) pseudo-contractive and accretive mappings extends the corresponding theory of Browder [14] involving compact perturbations. Detailed proofs of these and other results will be given elsewhere. Various surjectivity results for ball-condensing perturbations of these mappings can be found in [8], [15], [16].

ACKNOWLEDGEMENT. The author is grateful to the National Research Council of Canada for supporting this research.

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